

Evaluation of the Community Aquatic Monitoring Program (CAMP) to assess the health of four coastal areas within the southern Gulf of St. Lawrence with special reference to the impacts of effluent from seafood processing plants

M.-H. Thériault^{1,2}, S. C. Courtenay^{1,2,3}, C. Godin¹ and W. B. Ritchie¹

¹Department of Fisheries and Oceans
Gulf Fisheries Centre, Oceans and Science Branch
P.O. Box 5030
Moncton, New Brunswick
E1C 9B6

²Département de Biologie
Université de Moncton
Moncton, Nouveau-Brunswick
E1A 3E9

³Canadian Rivers Institute
University of New Brunswick
Fredericton, New Brunswick
E3B 6E1

2006

**Canadian Technical Report of
Fisheries and Aquatic Sciences 2649**



Fisheries
and Oceans

Pêches
et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

i

Canadian Technical Report of
Fisheries and Aquatic Sciences 2649

2006

**Evaluation of the Community Aquatic Monitoring Program (CAMP) to assess the
health of four coastal areas within the southern Gulf of St. Lawrence with special
reference to the impacts of effluent from seafood processing plants**

by

Thériault, M.H.^{1,2}, Courtenay, S.C.^{1,2,3}, Godin, C.¹ & Ritchie, W.B.¹

¹Department of Fisheries and Oceans
Gulf Fisheries Centre, Oceans and Science Branch
P.O. Box 5030
Moncton, New Brunswick
E1C 9B6

²Département de Biologie
Université de Moncton
Moncton, Nouveau-Brunswick
E1A 3E9

³Canadian Rivers Institute
University of New Brunswick,
Fredericton, New Brunswick
E3B 6E1

© Her Majesty the Queen in Right of Canada, 2006.
Cat. No. Fs 97-6/2649E ISSN 0706-6457

Correct citation for this publication is:

Thériault, M.H., S.C. Courtenay, C. Godin and W.B. Ritchie. 2006. Evaluation of the Community Aquatic Monitoring Program (CAMP) to assess the health of four coastal areas within the southern Gulf of St. Lawrence with special reference to the impacts of effluent from seafood processing plants. Can. Tech. Rep. Fish. Aquat. Sci. 2649: vii + 60 p.

TABLE OF CONTENTS

LIST OF TABLES.....	IV
LIST OF FIGURES.....	V
LIST OF APPENDIX.....	VI
RÉSUMÉ.....	VII
ABSTRACT.....	IX
INTRODUCTION.....	1
METHODS AND MATERIALS.....	3
STUDY SITES.....	3
<i>Lamèque Bay</i>	3
<i>Scoudouc River estuary</i>	4
<i>Basin Head lagoon</i>	4
<i>Antigonish Harbour</i>	5
STATION SELECTION.....	5
COMMUNITY SAMPLING.....	5
HABITAT CHARACTERIZATION.....	6
STATISTICAL ANALYSES.....	7
<i>Univariate analyses</i>	7
<i>Multivariate analyses</i>	7
RESULTS.....	9
DESCRIPTIVE RESULTS.....	9
UNIVARIATE RESULTS.....	10
<i>Inter-site differences</i>	10
<i>Intra-site differences</i>	11
MULTIVARIATE RESULTS.....	13
<i>Inter-site differences</i>	13
<i>Intra-site differences</i>	13
ENVIRONMENTAL DESCRIPTION OF THE STUDY SITES.....	16
SEDIMENT ANALYSES.....	17
LINKING ENVIRONMENTAL DATA WITH COMMUNITY AND POPULATION STRUCTURE.....	18
DISCUSSION.....	20
COMMUNITY AQUATIC MONITORING PROGRAM (CAMP).....	20
PATTERNS OF RICHNESS AND ABUNDANCE.....	24
RELATING COMMUNITY STRUCTURE TO ENVIRONMENTAL DESCRIPTORS.....	25
SEAFOOD PROCESSING PLANT EFFECTS.....	26
RESEARCH RECOMMENDATIONS.....	28
CONCLUSION.....	29
ACKNOWLEDGEMENTS.....	30
REFERENCES.....	31

LIST OF TABLES

Table 1. Total abundance of each species (young-of-the-year (YOY) and adult) caught in Lamèque Bay, Scoudouc River estuary, Antigonish Harbour and Basin Head lagoon between July and October, 2003.....	36
Table 2. Results of the two-way analysis of similarity (ANOSIM) comparison for the fish and crustacean community among the different sites (i.e., Lamèque Bay, Scoudouc River estuary, Basin Head lagoon and Antigonish Harbour) and the different months (i.e., July to October) in 2003. Values obtained by the ANOSIM are Global R statistic and the pairwise comparison R statistic. Significant levels are in parentheses.	38
Table 3. Analysis of similarity (one-way ANOSIM) for the fish and crustacean community for each site individually among the stations (months being pooled as replicates) and among the months (station being pooled as replicates). Values obtained by ANOSIM are Global R statistic and the pairwise comparison R statistic. Significant levels are in parentheses.	39
Table 4. SIMPER results indicating the top eight species contributing most to the average dissimilarity or the top species contributing up to 90% dissimilarity between summer and fall for all four sites.	40
Table 5. Spatial and temporal differences in percent organic content, percent moisture content and Mean Grain Size (MGS) of surficial sediment samples for each site.	42
Table 6. BIOENV results giving the combination of environmental variables yielding the best match between the biotic and abiotic similarity matrices for each month in Lamèque Bay and Scoudouc River estuary. Values in brackets are Spearman weighted rank correlation coefficients (ρ_w) for each environmental variable taken singly. The Global ρ_w is the global value for the best combination of environmental variables. Distance refers to distance from the outfall of a fish processing plant. ..	44
Table 7. Lamèque Bay Spearman rank correlation results between the dominant species, the species richness, the total abundance of animals and different environmental factors.....	45
Table 8. Scoudouc River estuary Spearman rank correlation results between the most dominant species, the species richness, the total abundance of animals and different environmental factors.	46
Table 9. Antigonish Harbour Spearman rank correlation results between the most dominant species, the species richness, the total abundance of animals and different environmental factors.	47
Table 10. Basin Head lagoon Spearman rank correlation results between the most dominant species, the species richness, the total abundance of animals and different environmental factors.	48

LIST OF FIGURES

- Figure 1. Map of the southern Gulf of St. Lawrence, showing the four sites where the CAMP was launched in 2003. 49
- Figure 2. Map showing the four study sites and their sampling stations sampled from July to October 2003. FP = fish plant. 50
- Figure 3. Mean species richness and abundance ($\pm$ 95% confidence interval) per beach seine haul at the four sites sampled in 2003. Groups sharing common letters are not significantly different ($p > 0.05$, Tukey test). Sample size are placed in parentheses (# stations x # months sampled). 51
- Figure 4. Mean species richness and mean abundance ($\pm$ 0.95 CI) captured per beach seine haul in Lamèque Bay among the months and the stations sampled. The sample size for each month is 10 (station being pooled as replicates) and for each station is 4 (months being pooled as replicates). Fish plant is located between stations 5 and 6. Groups sharing common letters are not significantly different ($p > 0.05$, Tukey test). 52
- Figure 5. Mean species richness and mean abundance ($\pm$ 0.95 CI) captured per beach seine haul in Scoudouc R. estuary among the months and the stations sampled. Sample sizes are in parentheses. Groups sharing common letters are not significantly different ($p > 0.05$, Tukey test). Fish plant is located at station 4. 53
- Figure 6. Mean abundance ($\pm$ 95% CI) captured per beach seine haul of A) Atlantic silverside, B) fourspine stickleback and C) mummichog in Scoudouc River estuary caught among the seven stations sampled (i.e., months being pooled as replicates) in 2003. Sample size is in parentheses. Groups sharing common letters are not significantly different ($p > 0.05$, Tukey test). Fish plant is located at station 4. 54
- Figure 7. Mean species richness and mean abundance ($\pm$ 0.95 CI) captured per beach seine haul in Antigonish Harbour among the months and the stations sampled. Sample sizes are in parentheses. Groups sharing common letters are not significantly different ($p > 0.05$, Tukey test). 55
- Figure 8. Mean species richness and mean abundance ($\pm$ 0.95 CI) captured per beach seine haul in Basin Head Lagoon among the months and the stations sampled. Sample sizes are in parentheses. Groups sharing common letters are not significantly different ($p > 0.05$, Tukey test). 56
- Figure 9. MDS plot of community data from Lamèque Bay (L), Scoudouc River estuary (S), Antigonish Harbour (A) and Basin Head Lagoon (B) at station 1 to 10 for Lamèque Bay and 1 to 7 for the three other sites in the month of July (J), August (A), September (S) and October (O). 57

Figure 10. MDS plot of the average (i.e., months being pooled) fish and crustacean community per stations at all four sites in 2003. Ellipses contain stations grouping together at 70% similarity in a cluster analysis (not shown). 58

Figure 11. Mean (+SE) temperature, salinity and dissolved oxygen from July to September at the four sites sampled. Numbers indicate sample size. Analyses were performed by site and bars sharing the same letters are not significantly different (Tukey $p > 0.05$). 59

LIST OF APPENDIX

Appendix 1. Detailed description of when and where species counts were curtailed at 300 in Lamèque Bay (L), Scoudouc River estuary (S), Antigonish Harbour (A) and Baie du Village (B) in 2003.....60

RÉSUMÉ

Thériault, M.H., S.C. Courtenay, C. Godin and W.B. Ritchie. 2006. Evaluation of the Community Aquatic Monitoring Program (CAMP) to assess the health of four coastal areas within the southern Gulf of St. Lawrence with special reference to the impacts of effluent from seafood processing plants. Can. Tech. Rep. Fish. Aquat. Sci. 2649: vii + 60 p.

En 2003, la section de l'intendance et des sciences environnementales du ministère des Pêches et Océans (MPO), Région du Golfe, ont développé ensemble un projet de surveillance de la communauté aquatique (PSCA) pour évaluer la santé écologique des estuaires et des baies de la région du sud du Golfe du St Laurent (sGSL). Ce projet pilote a débuté en 2003 à quatre sites, soit : dans la baie de Lamèque au Nouveau-Brunswick (N.-B.), dans l'estuaire de la rivière Scoudouc à Shédiac N.-B., dans la lagune de Basin Head à l'Île du Prince Edouard (I.P.E.) et dans le havre d'Antigonish en Nouvelle-Écosse (N.-É.). Les objectifs de cette étude étaient : 1) quantifier la variation spatio-temporelle de la communauté de poissons et de crustacés échantillonnée pour élaborer un programme de surveillance de la santé des baies et des estuaires du sGSL et 2) évaluer les impacts des effluents d'usine de transformation de produits marins sur la faune littorale puisque les stations d'échantillonnage dans la baie de Lamèque et dans la rivière Scoudouc ont été sélectionnées à proximité d'une usine de transformation de produits marins.

Aux quatre sites, la communauté de poissons et de crustacés diurnes a été échantillonnée mensuellement de juillet à octobre 2003 avec une seine de plage de 30 m X 2 m. Les poissons et crustacés capturés par tirée de seine ont été identifiés, comptés et remis à l'eau. La caractérisation de l'habitat pour chacune des stations incluait : des paramètres de l'eau, la couverture végétale et l'analyse des sédiments superficiels.

La structure des communautés différait parmi les quatre sites, mais était dominée par six espèces de poissons représentant ensemble 98% de la quantité totale de poissons capturés aux quatre sites. Ces espèces en ordre d'importance sont : le choquemort (*Fundulus heteroclitus*), la capucette de l'Atlantique (*Menidia menidia*), l'épinoche à quatre épines (*Apeltes quadracus*), l'épinoche à trois épines (*Gasterosteus aculeatus*), l'épinoche à neuf épines (*Pungitius pungitius*) et la fondule barée (*Fundulus diaphanus*). Les résultats de l'estuaire de la rivière Scoudouc ont démontré une augmentation d'animaux près de

l'usine de transformation de produits marins comparativement aux autres stations du même estuaire, indiquant possiblement un enrichissement du milieu. De plus, la richesse en espèce et l'abondance d'organismes capturés dans la baie de Lamèque étaient inférieures aux trois autres sites.

Les analyses multivariées ont indiqué des différences saisonnières et les analyses SIMPER ont démontré que le choquemort, la capucette de l'Atlantique et la crevette grise de sable étaient les espèces discriminantes entre l'été et l'automne à tous les quatre sites. Différents paramètres environnementaux ont été corrélés avec l'assemblage de la communauté de poissons et de crustacés tels que: la température, la salinité, le recouvrement de la zostère (*Zostera marina*) et des algues macroscopiques. Durant certains mois, la communauté de poissons et de crustacés retrouvée dans la baie de Lamèque et dans l'estuaire de la rivière Scoudouc corrélait significativement avec la proximité de l'exutoire des usines de transformation de produits marins.

Enfin, les résultats préliminaires de ce projet ont permis de formuler des recommandations pour la continuité du PSCA et le développement d'un programme de recherche pour évaluer les effets des effluents des usines de transformation de produits marins sur la faune estuarienne.

ABSTRACT

Thériault, M.H., S.C. Courtenay, C. Godin and W.B. Ritchie. 2006. Evaluation of the Community Aquatic Monitoring Program (CAMP) to assess the health of four coastal areas within the southern Gulf of St. Lawrence with special reference to the impacts of effluent from seafood processing plants. Can. Tech. Rep. Fish. Aquat. Sci. 2649: vii + 60 p.

In 2003, the Stewardship and Environmental Science Sections of the Department of Fisheries and Oceans (DFO) Gulf Region developed a Community Aquatic Monitoring Program (CAMP) to determine and subsequently monitor the ecological health of estuaries and bays in the southern Gulf of St. Lawrence (sGSL). The program was designed for, and conducted by, community based environmental groups at each site. This pilot project was launched at four sites: Lamèque Bay in New Brunswick (NB), Scoudouc River estuary in Shediac NB, Basin Head Lagoon in Prince Edward Island (PEI) and Antigonish Harbour in Nova Scotia (NS). The objectives of this study were: 1) quantify spatio-temporal variance in the littoral fauna as a first step towards a monitoring program for estuarine health; and 2) evaluate the impacts of seafood plant effluent on littoral fauna because sampling stations in Lamèque Bay and Scoudouc River estuary were selected in close proximity to a seafood processing plant.

The fish and crustacean communities of all four sites were sampled monthly between July and October 2003 with a 30 x 2 m beach seine. Fish and crustaceans captured per beach seine haul were identified, counted and released back to the water. Habitat characterization for each station included: water parameters, vegetation coverage and surficial sediment analysis.

The community structure differed among the four sites but was dominated everywhere by six fish species which contributed 98% of the total fish catch including in order of importance: mummichog (*Fundulus heteroclitus*), Atlantic silverside (*Menidia menidia*), fourspine stickleback (*Apeltes quadracus*), threespine stickleback (*Gasterosteus aculeatus*), ninespine stickleback (*Pungitius pungitius*) and the banded killifish (*Fundulus diaphanus*). Results from the Scoudouc River estuary revealed significantly more animals near the seafood processing plant, than elsewhere in the same estuary, possibly indicating an enrichment effect. Fewer species and lower abundance of animals were captured in Lamèque Bay compared to the three other sites.

Multivariate analyses indicated seasonal differences, and SIMPER analyses showed that mummichog, Atlantic silverside and the sand shrimp were discriminating species between summer and fall at all four sites. A number of habitat parameters were correlated with the community composition including: temperature, salinity, eelgrass (*Zostera marina*) and algae coverage. Within some months, community differences among stations in Lamèque and Scoudouc significantly correlated with proximity to the fish plant outfall. Results of this preliminary survey were used to formulate recommendations for an expanded CAMP program and a research program into the effects of seafood plant effluent on nearshore estuarine fauna.

INTRODUCTION

In 1997, Canada passed the *Oceans Act* to better manage and protect estuarine, coastal and marine environments. In order to effect the changes brought forth by the *Oceans Act*, Fisheries and Oceans Canada is working with government, industry and community groups to promote a greater understanding and improve conservation of these valuable ecosystems, particularly through stewardship. In 2003, the Stewardship and Environmental Science Sections (DFO, Gulf Region) developed a monitoring program as a tool to determine the ecological health of bays and estuaries in the southern Gulf of St. Lawrence (sGSL). Entitled the Community Aquatic Monitoring Program (CAMP), this pilot project was designed to be user-friendly requiring little technical expertise or infrastructure, and ideally suited to local community groups with some support from DFO. The program included a monthly survey of fish and crustacean species captured and released using a 30m by 2m beach seine at various locations within an estuary or a bay. It also required a description of the habitat using environmental parameters including temperature, salinity, and dissolved oxygen of the nearshore water, coverage by aquatic macrophytes and macroalgae, and sediment analyses (mean grain size – MGS, organic content and moisture content). In 2003, a specific issue addressed by the CAMP program was the effect of seafood processing plants. Two of the four sites studied in the first year were receiving environments of effluent from seafood processing plants.

Many studies have used the community assemblage as a key indicator to calculate the index of biological integrity (IBI). This method uses a suite of metrics that calculates the capacity of a site to support and maintain a balanced biotic community comparable to an unaffected natural habitat (Karr 1981; Fausch et al. 1984; Minns et al. 1994). Fish community assemblages have also been used as a monitoring tool for evaluating the biological effects of point source pollution such as effluents discharged by pulp and paper mills and sewage treatment plants (Neuman and Karås 1988; Grigg 1994; Adams et al. 1996; Otway et al. 1996a and b; deBruyn et al. 2002). Until now, no environmental impact assessments have been done on the fish and crustacean community living in the receiving environment of fish processing plant effluents. However, several studies have characterized the effluent and have carried out toxicity testing on them which have

demonstrated toxicity to biota (Wells and Schneider 1975; NovaTec Consultants Inc and EVS Consultants 1994; AMEC Earth & Environmental limited 2003).

Fish communities have been selected in this study as a potential indicator of environmental and ecological change within estuaries. The key response variables that are directly and frequently influenced by human activity are numbers of fish species and their relative abundance. The advantages of using the fish as a potential indicator of the environmental health is that stress effects may be inferred from the absence of a particular species in the environment, and substantiated by using specific species (i.e. sentinel species) in laboratory assays to verify depressed growth, survival and reproductive success. CAMP also required that fish and crustaceans be easily identified in the field and that sampling be conducted in a non-destructive manner (i.e., capture-release). The general public would be more likely to relate to consequences of environmental change on the fish and crustacean community which is more visible and familiar than the smaller and more hidden benthic invertebrates or algae that can take longer to identify (Karr 1981; Karr 1987). Sampling fish also avoided working in potentially contaminated sediments.

Recent observations indicate that some sGSL coastal areas receiving fish processing plant effluent have become severely degraded as a result of eutrophication (Morry et al. 2003, Roy Consultants Ltd. et al. 2003). In Lamèque Bay, nutrient pollution created primarily by one of NB's largest seafood processing plants is believed to be responsible for the degradation of the littoral benthos. High nutrient input by the seafood processing plant led to the formation of sea lettuce (*Ulva lactuca*) algal blooms which rotted onshore, creating anoxic sediment and releasing high levels of hydrogen sulfide gas (Roy Consultants Ltd. et al. 2003). Damage to the fish habitat and risk to human health resulted in calls for greater attention to the effects of seafood plant effluents in this bay and elsewhere.

In Canada, certain land-based sources of marine pollution such as the pulp and paper mills and metal mining sectors are under strict regulations which require them to conduct Environmental Effects Monitoring (EEM) studies on their receiving environments (Lowell et al. 2003). Such rigorous standards have not yet been implemented for seafood processing plants. The last guidelines applied to Fish Processing Operations Liquid Effluent were promulgated in the mid 1970s (Environment Canada 1975). The major

active guidelines for the control of liquid effluents from fish, shellfish and fish meal processing operations include: 1) removal of solids by a 0.71 mm mesh screen; 2) a well designed outfall discharging below low tide; 3) recovery of certain high concentration wastes such as bloodwater, stickwater, pressliquor and, 4) «good housekeeping» (Environment Canada 1975). Little has been done until now to either assess the individual and cumulative impacts of fish plant operations or to identify suitable standards for their effluents (Morry et al. 2003).

In this paper we report the results of the first year of data collected under CAMP through analyses of the fish and crustacean communities at 4 different sites. The objectives of this study are to: 1) to quantify spatial and temporal variance in littoral community parameters, both within and between estuaries of the sGSL and 2) to test if the community composition (i.e., diversity and abundance) near fish plants differs from other stations within the same bay or estuary and compared to bays and estuaries without processing plants. The initial objective is a first step towards testing the hypothesis that the littoral fish/crustacean community reflects environmental health of the coastal sGSL.

METHODS AND MATERIALS

STUDY SITES

Lamèque Bay

Four sites throughout the sGSL were selected for sampling in 2003 (Fig. 1). Lamèque, in northeastern New Brunswick (NB), has one of the largest seafood processing plants in NB (Fig. 2). Lamèque Bay has an average depth of 2.5-3 m with a dredged channel maintained at a minimum depth of 5.5 m. The bay covers an area of 10.3 km² with Jean-Marie Creek emptying in the north and a salt marsh occupying the south. Lamèque Bay empties into the Shippagan Bay which in turn empties in the Chaleur Bay (Roy Consultants Ltd. et al. 2003). The seafood processing plant in Lamèque is located at the wharf and processes shellfish, including crab, lobster and shrimp as well as a range of finfish such as herring, mackerel, cod and flounder (Ministry of Business New Brunswick 2003). It also produces fish meal. When in operation, from April to October, the plant discharges effluents intermittently during the day depending on the amounts of product processed. The plant discharges an average of 2500 m³/day of effluent (i.e., contact and

non-contact cooling water) through an outfall located at the southeastern side of the fishing vessel harbour (Roy Consultants Ltd. et al. 2003). The end of the pipe was directly in the breakwater and did not extend into the bay. The pipe was submerged at high tide and was visible at low tide. Beach seining at the end of the pipe in Lamèque Bay was impossible because no beach was accessible to haul our seine and the water was too deep due to the dredged channel.

Scoudouc River estuary

Scoudouc River estuary located in Shediac NB has a cooked and raw lobster processing plant that discharges approximately 568 m³/day of effluent 15 m from shore (AMEC Earth & Environmental Limited 2003) (Fig. 2). The plant is in operation from May to December and discharges effluents intermittently during the day depending on the amount of lobster processed. The effluent is a mix of fresh and salt water that has been cooled before discharge (G. Maillet, 261 Main St. Shediac, N.B. E4P 2A6, pers. comm.). The Scoudouc River estuary is shallow (i.e., 0.6-1.2 m at low tide) with scattered patches of vegetation such as eelgrass beds (*Zostera marina*) and sea lettuce. Scoudouc River estuary empties into the Shediac Bay which then drains into the Northumberland Strait. Upland areas of the Scoudouc River watershed are primarily used for agriculture, as compared to the Scoudouc estuary which borders on a residential and commercial area.

Basin Head lagoon

Basin Head lagoon is located on the south side of the north-eastern tip of Prince Edward Island (PEI) and was selected because it is the first Marine Protected Area (MPA) in the sGSL (Fig. 2). Basin Head is a marine lagoon of 0.59 km² surrounded by land and separated from the ocean by a barrier sand dune. The lagoon is comprised of a 0.24 km² main basin where most of the sampling was done, a 2.9 km long northeast arm and a 0.5 km channel leading to the ocean. The total watershed (17.5 km²) is used primarily for agriculture (40%) (Island Nature Trust 2001). Basin Head lagoon is shallow with a maximum depth of 3.3 m (Sharp et al. 2003). The major source of fresh water to Basin Head is a stream located at the northwest end of the main basin (Fig. 2). Basin Head lagoon also hosts a large population of invasive green crabs (*Carcinus maenas*) and a

unique strain of Irish moss (*Chondrus crispus*), the latter found mainly in the shallow water of the northeast arm (Sharp et al. 2003).

Antigonish Harbour

Antigonish Harbour, located on the northeast shore of Nova Scotia (NS), was chosen because of recent concerns regarding the health of the harbour, including a decrease in eelgrass beds (Fig. 2). The harbour is a brackish tidal area, separated from the ocean by barrier beaches and has areas of cordgrass (*Spartina sp.*) in salt marshes and eelgrass in the shallow flats. It is also shallow with the deepest part of the channel being less than 9.2 m deep. The harbour supports a population of green crabs. The western side of the harbour has farms, an abattoir and more dwellings than the relatively sparsely populated eastern side. The town of Antigonish is located at the head of the harbour where the town's water treatment plant (i.e., aerated lagoon) discharges into the Rights River and then empties into the harbour. The major rivers emptying in the harbour are Rights River, West River and South River.

STATION SELECTION

Within each site, seven to 10 stations were distributed throughout the bay or estuary studied. A requirement of the study was for each station to contain eelgrass beds or to be favorable habitats for eelgrass. All stations within a site shared approximately the same depth, salinity, temperature, sedimentation type and vegetation. Easy access to the stations and ability to sample by beach seine were among the factors that determined the location of stations.

COMMUNITY SAMPLING

Monthly daytime sampling of coastal fish and crustaceans was done at each site between the 7th July and 22nd October 2003, on a total of four sampling periods. Fish and crustaceans were collected with a 30 m long by 2 m high beach seine of 6mm mesh size with a central bag of 2 m high by 2 m wide and 1 m deep. This method was selected because it is relatively non destructive and one of the most effective for capturing small-bodied fish (200 mm or less) typically abundant in bays and estuaries (Methven and Schneider 1998; Griffiths 2001). However, beach seining among estuaries could increase

chances to disperse invasive species. To prevent spread of invasive species among estuaries, we soaked the net overnight in a mixture of water and white vinegar (4L) and hung the seine when possible in the sun to dry completely.

At each site and on each sampling date, one beach seine haul per station was done covering the entire water column sweeping an area of approximately 225 m². The seine was deployed 15 m perpendicular to shore and then towed 15 m parallel to shore and hauled back to shore. Sampling was usually done around high tide (± 3 h). The captured fish and crustaceans were placed in a fish tub (0.9 m x 0.6 m) previously drilled with small holes to allow water exchange and the tub was placed in the bay or estuary studied. Animals were identified to species most of the time and to genus when closely related species could not be distinguished. The organisms were then separated by developmental stage (i.e., young-of-the-year (YOY) or adult), counted to a maximum of 300 individuals per species, and released to minimize impact. Separation by developmental stage was accomplished with visual length examination for the months of September and October only. Young-of-the-year fish were usually under 2 cm long.

HABITAT CHARACTERIZATION

Environmental data were collected monthly at each station to characterize habitat. The water temperature (± 0.01 °C), salinity (± 0.01 ppt) and dissolved oxygen (± 0.01 mg/L) were taken with a portable handheld multiprobe YSI 556. The YSI probe was submerged approximately at mid-depth in the center of the sampled area.

Surface sediment samples approximately 10 cm deep were collected monthly with a garden trowel (21 cm x 10 cm) from each station within the area beach seined and from water less than 1 m deep. The sediments were preserved frozen at -20°C until analyzed. In the laboratory, moisture content was determined as the difference in weight before and after drying at 70°C for 24 h (standardized time). Organic content was calculated as the difference in weight before and after burning the sediments in a muffle furnace at 500°C for 1 h (standardized time). Grain size distribution per sample was determined from 10 min shaking (standardized time) with a mechanical sieve shaker with six different sieve sizes: >2 mm (very coarse sand), >1 mm (coarse sand), >500 μ m (medium sand), >250 μ m (fine sand), >125 μ m (very fine sand), >63 μ m (coarse silt) and <63 μ m (silt) (Higgins and Thiel

1988). The MGS was then calculated from the cumulative frequency curves established with the grain size distribution.

Macroalgae and macrophyte coverage was measured with a 50 cm X 50 cm quadrat divided into four equal sub-quadrats. The quadrat was thrown three times within the beach seine station. At each throw, each sub-quadrat was viewed and percent coverage by each macrophyte and macroalgae type was estimated. A mean percent coverage was calculated for each quadrat.

STATISTICAL ANALYSES

Univariate analyses

Analysis of variance (ANOVA) was used to compare spatial (i.e., within and among sites) and temporal differences (i.e., among the months) in the total abundance of animals and species richness as well as for the environmental variables. Data were examined for normality and homoscedasticity by probability plot and $F_{\max}$ test, respectively. Data were transformed to $\log_{10}(x+1)$ when normalization was required. Tukey multiple comparison tests were used when significant differences were found among groups. Significance level was set at $p = 0.05$. Univariate statistics and descriptive statistics were completed with SYSTAT 11 software ® (2004 SYSTAT Software Inc., Point Richmond, CA, USA).

Spearman rank correlation was used to test association of environmental variables with dominant species. We also tested whether the abundance and species richness correlated with any of the environmental variables. These simple Spearman rank correlations were performed with the SPSS software version 8.0 ® (1997 SPSS Inc.).

Multivariate analyses

Descriptive multivariate analyses were calculated with PRIMER 5.2.9. software ® (2002 PRIMER-E Ltd., Plymouth, UK). Data on the total number of animals captured were square root transformed to minimize the effect of the few dominant species and to include the effect of the rare species (Cao et al. 2001).

Transformed abundance data were used to generate a Bray-Curtis similarity matrix. The matrix contains similarity coefficients (S) between each pair of samples defined to take the values in the range of 0 to 100%. When S equals 100%, the two samples are totally

similar and $S = 0$ when two samples are completely dissimilar (Clarke and Warwick 2001). The Bray-Curtis similarity matrix was then used to calculate the ANOSIM (analysis of similarity) which depends on the relative order (i.e., ranking) of the similarity coefficients in the Bray-Curtis similarity matrix, rather than their absolute values. The ANOSIM determined whether the fish and crustacean assemblages differed statistically between the sites, stations and months. The ANOSIM test statistic, R , is based on the ratio of the between-group to within-group similarity ranking and ranges from 0 to 1, with the value indicating the degree of dissimilarity (1 = completely dissimilar; 0 = completely similar). Pairwise comparison tests are also calculated which generate an R value and a significance (p) value for each possible pair of comparisons. The importance of the pairwise tests is not so much the significance level, which can be low because of few replicates in each group, but rather the R value which provides an absolute dissimilarity measure among the samples on a scale of 0 (indistinguishable) to 1 (completely dissimilar) (Clarke and Gorley 2001).

A non-metric Multi-Dimensional Scaling (MDS) graphic was used to visualize the spatial relationships between the variables. The ranks of the Bray-Curtis similarity matrix are the only information used to generate an MDS. An MDS graph constructs a map of the samples in a specific number of dimensions (2-dimensions or 3-dimensions) which attempts to satisfy all the conditions imposed by the rank similarity matrix. The relative distance between samples is interpreted as a measure of their similarity. Points that are close together represent samples that are very similar in species composition, and points that are far apart correspond to very different communities. There is also a certain level of stress which is a measure of accuracy in representation of the MDS. By definition, stress level increases with reduced dimensionality and also with increasing quantity of data. The acceptance level of stress for a 2-D MDS graph is set to < 0.2 , indicating that the MDS is a good to excellent representation with minimal risk of misinterpretation (Clarke and Gorley 2001).

The BIOENV analysis was used for matching biotic data to environmental patterns. This method involves the following general steps: 1) construct a fixed similarity matrix of the animal assemblage among all stations, 2) construct multiple similarity matrices of the abiotic environmental variables among all stations for each abiotic variable singly, all possible pairs of abiotic variables, all possible triplets and so on until all possible matrices

of abiotic environmental data are constructed for all permutations. BIOENV then searches for the abiotic similarity matrix that is the best match with the biotic similarity matrix. The assumption is that the suite of abiotic variables selected best 'explains' the fish pattern found at the stations (Clarke and Ainsworth 1993). The BIOENV method is based on the rank correlation computed between the 2 matrices (e.g., Bray-Curtis similarity matrix for the biotic variables and the normalized Euclidean distance for the abiotic variable). This method does not prove causality, but only suggests a relationship and the strength of that relationship. It is above all, an exploratory tool that helps to identify potential agents that shape the community structure (Clarke and Ainsworth 1993).

The BIOENV biotic and abiotic matching process was performed by calculating the weighted Spearman rank coefficient (ρ_w) between the biotic and all possible abiotic similarity matrices (Clarke and Ainsworth 1993). The weighted rank correlation is different from the standard Spearman rank correlation because it includes a weighting term in the dominator of the equation that down-weights the contribution of large dissimilarities between distant pairs of sites. This transformation has the effect of improving the correlation of paired biotic / abiotic similarity matrices with high numbers of co-occurring low ranks while lessening the importance of high-ranking sites (Clarke and Ainsworth 1993).

RESULTS

DESCRIPTIVE RESULTS

A minimum total of 50,330 fish and crustaceans representing 22 species were counted at the four study sites between July and October 2003 (Table 1). This total number considerably under-estimates the true abundance of total animals caught because counting was stopped at 300 for very abundant species in each beach seine haul. The species that were curtailed at 300 and under estimated were: the threespine stickleback (*Gasterosteus aculeatus*), fourspine stickleback (*Apeltes quadracus*), mummichog (*Fundulus heteroclitus*), Atlantic silverside (*Menidia menidia*) and the sand shrimp (*Crangon septemspinosa*) (Appendix 1 indicates when and where these species were curtailed). Eleven species were common to all four sites. The green crab, an invasive species, and the northern pipefish (*Syngnathus fuscus*) were caught exclusively in Basin Head lagoon and Antigonish Harbour. Juvenile striped bass (*Morone saxatilis*) was caught only at Lamèque

Bay. These fish had probably migrated from the Miramichi estuary because all evidence to date suggests that Miramichi is the only spawning site for striped bass in the sGSL (Robichaud-LeBlanc et al. 1996; Robinson et al. 2001; Douglas et al. 2003). The American eel (*Anguilla rostrata*), American sand lance (*Ammodytes americanus*) and windowpane (*Scophthalmus aquosus*) were only caught in Antigonish Harbour (Table 1). The greatest number of species (fish and crustaceans) was caught in Antigonish (21 species), followed by Basin Head lagoon and Scoudouc River estuary (16) and finally Lamèque Bay (14).

Of 17 fish species captured, six species contributed 98% of the total fish catch and the other fish individually represented less than 1%. These six fish species in order of importance were: mummichog, Atlantic silverside, fourspine stickleback, threespine stickleback, ninespine stickleback (*Pungitius pungitius*) and banded killifish (*Fundulus diaphanus*). Forty two percent of the catch was comprised of the mummichog and 32% of the Atlantic silverside, and again, with absolute counts the true dominance of these two species would have been even more pronounced.

Five crustacean species were caught over the course of the study. The sand shrimp (*Crangon septemspinosa*) was the most abundant representing 88% of the total crustacean catch. The grass shrimp (*Palaemonetes vulgaris*) was the second most abundant representing 7% of the total crustacean catch. Within the crab species, the green crab, found exclusively in PEI and NS, was the most abundant comprising 86% of the total catch of crabs, but representing only 4% of the total catch of crustaceans (including crab and shrimp species). Fifty nine percent of the total green crab came from Antigonish Harbour and the other 41% from Basin Head lagoon.

UNIVARIATE RESULTS

Inter-site differences

Mean species richness differed significantly among the four sites ($F_{3,102} = 28.89$, $p < 0.001$) but not among the months sampled and no interaction was found between these two variables. Lamèque Bay had fewer species than the three other sites and Basin Head lagoon had significantly more species than Scoudouc River estuary (Fig. 3). The total number of organisms caught differed significantly among all four sites ($F_{3,114} = 7.23$, $p < 0.001$), Lamèque Bay had fewer fish and crustaceans than Basin Head lagoon and

Antigonish Harbour (Fig. 3). No difference in the total number of animals caught was found among the four months sampled and no interaction was found between these variables.

Intra-site differences

Lamèque Bay

The species richness and the total number of animals caught at the station closest to the fish plant in Lamèque Bay (i.e., station 6) did not differ significantly from the other stations located further away (months pooled as replicates) (Fig. 4).

Temporal differences were shown in Lamèque Bay. Species richness was significantly greater in July than in August and October ($F_{3,35} = 6.07$, $p < 0.002$, Tukey < 0.05) (Fig. 4). On average, 5.5 ± 0.6 (SE; $n = 10$) species per beach seine haul were caught in July compared to 4.3 ± 0.4 ($n = 10$) species in August and 3.8 ± 0.5 ($n = 10$) species in October. In July, two to three species of sticklebacks were caught per station and mummichog, Atlantic silverside and sand shrimp were also caught at almost every station. One exception occurred in July; station 7 only caught one adult mummichog.

Total number of animals captured was significantly greater in August and September than in July and October ($F_{3,36} = 10.27$, $p < 0.001$, Tukey < 0.05) (Fig. 4). In September, the mean abundance of animals caught per station was 479.1 ± 93.5 (SE; $n = 10$) followed by August (427.8 ± 60.1 ; $n = 10$), July (169.0 ± 46.7 ; $n = 10$) and October (111.4 ± 34.7 ; $n = 10$). This higher abundance in August and September was mostly contributed by recruits found in September such as YOY mummichog and silverside. Adult silverside and mummichog also contributed to the greater abundance in August and September.

Scoudouc River estuary

Significantly more animals were caught at the fish plant (i.e., station 4) and approximately 130 m upstream from the outfall (i.e., station 3) than at stations 5 and 6 ($F_{6,19} = 5.59$, $p = 0.002$) (Fig. 5). After performing a series of univariate statistics with different species, only two species were shown to contribute to the greater abundance of animals near the fish plant and at station 3. The total number of silverside (adults and YOY) was

greater near the fish plant than at all other stations except station 3 ($F_{6,19}=5.94$, $p=0.001$; Tukey test, $p<0.05$) (Fig. 6). The fourspine stickleback was also more abundant at station 3 than station 2, 5 and 7 ($F_{6,19}=4.61$, $p=0.005$; $p<0.05$ Tukey) and did not differ from station 1 and 4 (i.e. fish plant) (Fig. 6). The mummichog was another species that was present in high abundance at station 3, station 7 and near the fish plant but no significant difference in the total abundance of mummichog was found among the stations (Fig. 6). All the other species did not differ significantly among the stations. Species richness did not differ spatially among the seven stations sampled in Scoudouc River estuary (Fig. 5).

No monthly differences were found in Scoudouc River estuary when analyzing the total abundance of animals and species richness (Fig. 5).

Antigonish Harbour

Species richness was significantly higher at station 4 (i.e., next to the harbour mouth) and station 6 (i.e., on Fallis Island) than at stations 1, 3 and 5 ($F_{6,20}=6.74$, $p=0.001$, Tukey test, $p<0.05$) (Fig. 7). Ten to twelve species were found every month at station 4 and 6 compared to three to eight species at station 1, 3 and 5. No spatial difference was found when analyzing the abundance (Fig. 7).

No monthly differences were found in Antigonish Harbour when analyzing the total abundance of animals and species richness (Fig. 7).

Basin Head lagoon

Spatial differences were found with the total abundance but not with the species richness. Basin Head lagoon had significantly more animals at station 1 than station 2, 3, 6 and 7 ($F_{6,17}=5.39$, $p = 0.003$, Tukey test, $p<0.05$) (Fig. 8). Sticklebacks, Atlantic silverside and sand shrimp contributed most to the high abundance near station 1 because they were more abundant in three out of four months sampled.

No monthly differences were found in Basin Head lagoon when analyzing the total abundance of animals and species richness (Fig. 8).

MULTIVARIATE RESULTS

Inter-site differences

ANOSIM testing between all 4 sites identified a significant difference in the fish and crustacean community assemblage (Table 2). The differences in the multiple comparison pairwise results ranged from large differences in the community assemblage between Basin Head lagoon and Scoudouc River estuary and between Basin Head lagoon and Lamèque Bay to smaller differences between Antigonish Harbour and Basin Head lagoon (Table 2). ANOSIM also found significant differences in the community assemblage among the 4 months sampled (Table 2). Large differences were shown between July - September and August - October, whereas smaller differences were found between September and October (Table 2). This shows a disparity between the beginning and the end of the sampling season.

Intra-site differences

One main pattern was apparent from the 2D-MDS figures from all four sites analyzed individually: a seasonal gradient from July to October (Fig. 9). The monthly differences were confirmed in Lamèque Bay, Scoudouc River estuary, Antigonish Harbour and Basin Head lagoon with the ANOSIM analysis showing significant differences among months (Table 3). Large differences were often seen between the beginning of the season and the end of the season. Furthermore, ANOSIM confirmed that there were no spatial differences among the stations within any of the four sites sampled (Table 3). The MDS plot showed no difference between the stations, perhaps due to high temporal variability among replicates (Fig. 9). To have a better visual understanding of how the stations could have clustered together, we performed a second set of MDS plots pooling our replicates (i.e., months) together to have only one point per station (Fig. 10). These plots can give us an idea of how the stations might have been separated if our replicates had been less variable and if more replicates per station had been sampled. Even though no significant spatial differences were found within each site, we can see that certain stations were more similar to each other than others (i.e., points closer together). The cluster analyses dendrogram (not shown in this report because it gives us the same results as an MDS)

allowed us to determine the different clusters illustrated in Figure 10. We selected an arbitrary similarity value of 70% to determine particular grouping samples. It is usually better to choose the smallest similarity values creating distinct groups because it indicates a stronger difference among the groups. Seventy percent similarity was the smallest value found at all four sites in our cluster analyses.

In Lamèque Bay, the MDS plot showed three groups among the stations. The MDS plot revealed a separation in the outer and inner bay (Fig. 10). Two groups were formed in the outer bay, one on each side, and most stations fit into one group in the inner bay. We performed a SIMPER analysis to determine which species contributed most to the dissimilarity between the outer and inner bay. In the outer bay, sand shrimp and adult mummichog were more abundant and in the inner bay, silverside (YOY and adult), YOY mummichog and adult fourspine stickleback were more abundant.

In Scoudouc River estuary, three groups were formed at 70% similarity. The fish plant (i.e., station 4) separated from all the other stations due to the high abundance of adult silverside, mummichog and threespine stickleback captured near the outfall (SIMPER analysis). Juvenile silverside and grass shrimp were also more abundant near the outfall than elsewhere. The separation of the fish plant site from stations 1-3 and 5-6 is particularly striking because it is geographically surrounded by those other stations. Station 7 was different from the other stations because it was only sampled from August to October and was a very sandy station that quickly dewatered on falling tides. Station 7 seemed to be used as a nursery area for the mummichog which was the dominant species captured. YOY mummichog were over six times more abundant at station 7 than near the outfall.

In Antigonish Harbour, the MDS showed the formation of three distinct groups at 70% similarity. Stations 1, 2, 3 and 4, all located closest to the harbour mouth, clustered together because of higher abundance of sand shrimp and green crab than the other stations (SIMPER analysis). Furthermore, the littoral faunal community at station 5, situated more inland and close to a freshwater input, appeared to differ from the other stations. The univariate statistics also suggested that station 5 differed from the other stations by having significantly fewer species than stations 4 and 6. On average, station 5 had 6.8 ± 0.9 (SE; $n = 4$) species per beach seine haul compared to 10.5 ± 0.3 (SE; $n = 4$) species at station 4 and 11 ± 0.6 (SE; $n = 3$) species at station 6. Sediments at station 5 released strong smells

of hydrogen sulfide gas which may have repelled certain species, though not mummichog (YOY and adult), fourspine stickleback (YOY and adult), silverside (YOY and adult) and adult ninespine stickleback which were more abundant than at the other stations according to the SIMPER analyses. Stations 6 and 7, located closest to Antigonish town at the inner part of the harbour, also grouped together and had higher abundance of killifish and grass shrimp than the other stations. Note that no specific point source pollution was located at any of our stations in Antigonish.

In Basin Head lagoon, four groups were formed at 70% similarity. Station 1, next to the boat launch separated from the other stations perhaps because more species and organisms were caught in all four months, except in July. Univariate statistics also showed that station 1 had significantly more animals (Fig. 8). According to SIMPER analyses, higher abundance of silverside (YOY and adult), adult threespine stickleback, adult ninespine stickleback, YOY fourspine stickleback and adult sand shrimp were present at station 1 compared to the other stations. Stations 4 and 5 clustered together perhaps because they were located closest to the freshwater input and because they had higher abundance of YOY and adult mummichog, adult fourspine stickleback and adult green crab than the other stations. Station 7 also separated from the other stations, possibly because it was located closer to the lagoon mouth where the current was greater, substrate was coarser and less vegetation and animals were present. Station 2, 3 and 6 grouped together and were similar possibly because they were all located on the east side of the lagoon where more juvenile flounder were found than at all other stations except station 1.

To determine which species contributed to the differences in assemblage between months as found using ANOSIM, a SIMPER analysis was performed. To simplify the comparisons among months, they were pooled into seasonal categories (i.e., July and August = summer; September and October = fall). The differences among the seasons were confirmed by an ANOSIM test for all four sites, Lamèque Bay ($R = 0.390$, $p < 0.001$), Scoudouc River estuary ($R = 0.662$, $p < 0.001$), Antigonish Harbour ($R = 0.495$, $p < 0.001$) and Basin Head lagoon ($R = 0.203$, $p = 0.005$). The SIMPER analysis indicated that Lamèque Bay had the highest average dissimilarity (68.79%) between summer and fall and that Basin Head had the least (49.67%). Table 4 indicates the most important discriminating species between summer and fall at all 4 sites sampled. In summary, YOY

mummichog and silverside and grass shrimp were more abundant in the fall than summer. Adult mummichog, silverside and threespine stickleback were more abundant in the summer. Sand shrimps and adult fourspine stickleback were abundant in both seasons.

ENVIRONMENTAL DESCRIPTION OF THE STUDY SITES

Temperature and dissolved oxygen differed significantly among the four sites sampled but salinity did not (Fig. 11). Lamèque Bay had significantly lower water temperature than Antigonish Harbour ($F_{3,114} = 3.73$, $p = 0.013$). In Lamèque Bay, the temperature ranged from 5.23 to 26.00°C with a mean of $16.24^{\circ}\text{C} \pm 1.04$ (SE; $n = 40$) during the sampling season. In Antigonish the temperature ranged from 13.50 to 25.80°C with a mean of $20.10^{\circ}\text{C} \pm 0.74$ (SE; $n = 27$). Basin Head lagoon had significantly higher dissolved oxygen (DO) than Antigonish Harbour ($F_{3,114} = 4.91$, $p = 0.003$). In Basin Head lagoon, the DO ranged from 7.93 to 16.18 mg/L with a mean of 10.58 ± 0.42 (SE; $n = 25$) compared to Antigonish Harbour DO ranging from 3.39 to 11.30 mg/L with a mean of 8.30 ± 0.31 (SE; $n = 27$).

Plant coverage and algae coverage also differed among the four sites sampled. Basin Head had significantly more plant coverage than the three other sites ($F_{3,102} = 8.518$, $p < 0.001$). Plant coverage was also higher in July than September ($F_{3,102} = 3.052$, $p = 0.032$). Finally no interaction was found between these two variables (sites and months). Lamèque Bay and Scoudouc River estuary had significantly more algae coverage than Antigonish ($F_{3,102} = 5.456$, $p = 0.002$) but no monthly differences nor interaction between site x month was found.

The four sites were analyzed individually to test if the temperature, salinity and DO differed spatially (i.e., station) and temporarily (i.e., month). In Lamèque Bay and Scoudouc estuary, the three environmental variables differed significantly among the months (Fig. 11) but no spatial differences were found indicating that the effluent coming from the fish processing plants did not seem to change the water chemistry.

In Antigonish Harbour and Basin Head lagoon, temperature was significantly lower in October than other months ($F_{3,23} = 50.61$; $p < 0.001$; $F_{3,23} = 27.94$; $p < 0.001$, respectively) (Fig. 11). In Antigonish the salinity was lower at station 7 compared to station 1, 2, 3 and 4 all located closer to the harbour mouth ($F_{6,20} = 6.41$, $p = 0.001$). In

Basin Head lagoon the DO was significantly higher in July than August, September and October ($F_{3,21} = 9.40$; $p < 0.001$) (Fig. 11).

Plant and algae coverage were also analyzed for each site individually to test for spatial and temporal differences (Table 5). In Lamèque Bay, more algae coverage was found in August than July. In Scoudouc River estuary, increase plant coverage was found in July than August. Plant and algae coverage in Antigonish differed significantly among the stations but not among the months. Tukey test showed that significantly more algae was present at station 7, located closest to the harbour head, compared to station 1, 2, 4 and 6. As for the plant coverage, the Tukey test was not able to detect which station differed. In Basin Head, plant and algae coverage also differed among the stations, but not among the months. More plants were found at station 1 and 6 compared to station 4 and 5 and increase algae were found at station 5 than station 2.

SEDIMENT ANALYSES

Univariate statistics were performed on the sediment data to investigate temporal and spatial variance. All the analyses were done on arcsine square root transformed data for percent organic content and moisture content. Two-way ANOVA did not find any difference in the organic content between the sites ($F_{3,89}=1.55$, $p=0.206$) but did find a significant difference among the months ($F_{3,89}=3.37$, $p=0.022$) and finally no interaction was found between these two variables. The organic content was significantly lower in July than in August and September (Tukey test).

Analyses by site were also performed to test for temporal and spatial difference in moisture content; organic content and mean grain size (see Table 5 for results). Temporal differences in organic and moisture content were rarely seen but when they occurred they were usually seen between the beginning of the season (July, August) and at the end of the season (September, October). These results suggest that sediment sampling could be focused at the beginning and at the end of the sampling season. Furthermore, lower organic content was usually found in erosional areas where currents were higher and particle size of sediments was larger (e.g. station 7 in Basin Head lagoon). Conversely, higher organic content was found in depositional areas where the currents appeared lower (not quantified

in this study) and sediments were finer, such as station 1 located in an inlet of Antigonish Harbour (Table 5).

Mean grain size (MGS, log transformed to follow a normal distribution) differed among the four sites when pooling all months together ($F_{3,108} = 11.56$, $p < 0.001$, Tukey, $p < 0.05$). MGS was coarser in Antigonish Harbour (mean = $1.162 \text{ mm} \pm 0.231 \text{ SE}$; $n = 27$) than in Lamèque Bay ($0.549 \text{ mm} \pm 0.069$; $n = 34$), Scoudouc River estuary ($0.391 \text{ mm} \pm 0.075$; $n = 26$) and Basin Head lagoon ($0.281 \text{ mm} \pm 0.014$; $n = 25$). Lamèque Bay also had significantly larger MGS than Scoudouc River estuary and Basin Head lagoon. When analyzing each site individually, significant differences were found between the stations within all four sites but not between the months (Table 5). In general, smaller MGS was found in low current areas, such as inlets, and coarser grain sizes were found in higher current areas such as channels.

LINKING ENVIRONMENTAL DATA WITH COMMUNITY AND POPULATION STRUCTURE

BIOENV procedures were performed to select a subset of abiotic environmental variables maximizing the weighted Spearman rank correlation (ρ_w) between the biotic and abiotic similarity matrices. Prior to analyses, Draftsman plots for each site confirmed the absence of collinearity among pairs of environmental variables ($r < 0.95$). When analyzing all four sites together, environmental variables included for the analyses were: water parameters (i.e., dissolved oxygen, temperature, and salinity), sediment parameters (i.e., % moisture content, % organic content and mean grain size) and vegetation parameters (i.e., % eelgrass coverage and % algae coverage). When % algae coverage was selected as an environmental variable structuring the community assemblage, a more detailed BIOENV analyses was performed using the different species of macroalgae recorded.

The environmental descriptors correlating most highly with the community assemblage when pooling the four sites were: water temperature and % algae coverage at $\rho_w = 0.111$. Taken separately, water temperature had a greater correlation ($\rho_w = 0.079$) than the % algae coverage ($\rho_w = 0.011$). A more detailed analysis was performed including the most common algae species (i.e., % sea lettuce and % *Enteromorpha* sp. coverage) which found that % *Enteromorpha* sp. had better correlation with the fauna matrix at $\rho_w = 0.210$ when the four sites were pooled.

The BIOENV analysis was then run between the fixed biotic similarity matrix for each site individually and the matrix of eight independent abiotic variables described above. Lamèque Bay and Scoudouc River estuary also had the distance from the fish plant included as an extra physical descriptor. In Lamèque Bay and Scoudouc River estuary, the best correlation results between the biotic and abiotic similarity matrices indicated that the community assemblage found at the stations changed with temperature at $\rho_w = 0.345$ for Lamèque Bay and at $\rho_w = 0.438$ for Scoudouc River estuary. Proximity to the fish plant was never influential at either site. However, the strong temporal variation reflected in the influence of temperature might have masked any spatial differences that existed. To test this hypothesis, a BIOENV analyses was performed for each site/month combination individually (Table 6). In these analyses, proximity to fish plant correlated significantly with community structure at Lamèque Bay in July and at Scoudouc estuary in August and October. Temperature and percent eelgrass coverage also showed a high correlation with community structure (Table 6).

In Antigonish Harbour, dissolved oxygen, salinity and percent organic content correlated best with the fish and crustacean community matrix at $\rho_w = 0.275$. When environmental variables were taken separately, dissolved oxygen had the highest correlation value ($\rho_w = 0.251$), followed closely by salinity ($\rho_w = 0.223$) and finally dissolved oxygen at ($\rho_w = -0.075$).

In Basin Head lagoon, the combination of environmental variables correlating best with the biota assemblages were salinity, MGS, % eelgrass and % algae coverage at $\rho_w = 0.216$. A second BIOENV analyses was performed with the different algae species which included: sea lettuce, *Enteromorpha* sp., *Fucus* sp., Irish moss and green filamentous algae. The combination of different environmental variables correlating best with the biotic matrix was: % sea lettuce coverage, temperature and MGS at $\rho_w = 0.407$. When the environmental variables were taken independently, the % sea lettuce coverage had the highest correlation value with biota structure at $\rho_w = 0.340$, followed by temperature $\rho_w = 0.085$ and the MGS $\rho_w = 0.021$.

At three out of four sites, the temperature was the variable correlating most highly with the community assemblage followed by salinity at two out of the four sites, underscoring the importance of these two variables.

Finally, Spearman rank correlation analyses were carried out at each site to assess the association between the different environmental variables and the dominant species as well as with the species richness and abundance (Tables 7, 8, 9, and 10). Results of these analyses support the finding that greater abundance of animals was found near the fish plant in Scoudouc River estuary and not in Lamèque Bay. Adult threespine stickleback and silverside were more abundant near the outfall in Scoudouc River estuary according to the Spearman rank correlation. In Lamèque Bay, temperature and salinity were most strongly correlated with distributions of several species. For example, greater numbers of threespine stickleback, mummichog and silverside were captured at high temperatures and YOY silverside at low temperatures. Species richness was reduced at higher salinity, which ranged from 17.7 to 29.0 ppt in Lamèque Bay and lower numbers of fourspine stickleback, threespine stickleback and mummichog were present at higher salinity.

In Antigonish Harbour, salinity was most strongly correlated with distribution of fauna and results indicated high abundance of sand shrimp and green crab at higher salinity and low abundance of fourspine stickleback and low species richness at higher salinity. Greater eelgrass coverage was associated with higher abundance of fourspine and threespine stickleback, but lower numbers of sand shrimp (Table 9).

In Basin Head lagoon, abundance of algae was positively correlated with numbers of fourspine stickleback, threespine stickleback, mummichog and green crab but negatively correlated with numbers of sand shrimp. In addition, temperature, MGS, moisture content, organic content and salinity also correlated with distributions of certain species in Basin Head lagoon (Table 10).

DISCUSSION

COMMUNITY AQUATIC MONITORING PROGRAM (CAMP)

The CAMP appears to be an efficient tool for providing an indication of the diversity and abundance of fish and crustaceans present in shallow and nearshore waters of the bays and estuaries of the sGSL. Spatial differences found among and within the sites indicated that regional and local differences exist in estuaries further supporting the concept that estuaries are highly variable (Whitfield and Elliot 2002). In addition, strong seasonal differences in the community assemblage were found in sGSL. Therefore, additional years

of data and a better understanding of the interactions between biotic and abiotic factors affecting the community structure in the estuaries will facilitate the understanding of the baseline variance and allow us to detect changes that exceed this baseline spatial and temporal variance.

Univariate statistics showed clear spatial differences among the four sites. Lamèque Bay showed lower species richness than the three other sites (i.e., 5 vs 7-9 species per beach seine haul). Significantly fewer animals per beach seine haul were also captured in Lamèque Bay compared to Antigonish Harbour and Basin Head lagoon. The multivariate statistics also detected large differences between Basin Head lagoon and Lamèque Bay.

Many reasons could explain why Lamèque Bay had lower species richness and abundance than the three other sites, the first being simply a latitudinal effect since Lamèque was the most northerly site sampled. On a larger geographic scale, reduced richness of fish species with increasing latitude is known to occur. Only six fish species comprised greater than 1% of the total fish catch in our study compared to 13 reported in Massachusetts (Hughes et al. 2002). Ayvazian et al. (1992) reported that species richness was lower in increasingly northern latitudes such as Wells Harbour, Maine (24 species found in total) compared to Waquoit Bay Massachusetts (48 species). The same kind of latitudinal differences among our four sites might explain why the lowest species richness was at the most northerly site. Though the distances between sites were smaller than those referred to in previous studies, significant differences existed between Lamèque Bay and the more southerly sites. Average temperature, for example, was lower in Lamèque Bay than the other three sites (i.e., 16°C vs 19-20°C). Many authors have linked seasonality in abundance and diversity of estuarine coastal fish assemblages to temperature (Targett and McCleave 1974; MacDonald et al. 1984; Szedlmayer and Able 1996; Marshall and Elliott 1998; Lazzari et al. 1999; Methven et al. 2001).

Low species richness and abundance in Lamèque could also be related to the high nutrient input from the seafood processing plant into the low flushing bay of Lamèque. Accumulation of waste due to the inadequate circulation and flushing of the bay could reduce the habitat quality leading to lower species richness and abundance. Another recent introduction to Lamèque Bay is bivalve aquaculture. It has been suggested that the structures used for bivalve aquaculture, such as the surface buoys, socks and mooring

ropes, might have caused considerable attenuation of wave energy that in the past swept clean the intertidal zone in front of the town of Lamèque (Roy Consultants Ltd. et al. 2003). In addition, historic flushing patterns may have been altered by the construction of a breakwater across the inner bay.

It is likely that multiple anthropogenic influences contributed to the degradation of Lamèque Bay including aquaculture (Lotze et al. 2003), the city's water treatment plant and the very high nutrient loading from the seafood processing plant. According to Roy Consultants Ltd. et al. (2003), the town sewage treatment facility contributes nutrient loading to Lamèque Bay because it lacks tertiary treatment, but the associated environmental effect is limited to negligible compared to the nutrient loading from the seafood processing plant. The relative contribution of these anthropogenic activities to the degradation of Lamèque Bay is still unknown but might explain in part why the species richness and abundance is lower relative to other sites sampled.

High counts of fish and crustaceans, especially young-of-the-year, were observed at certain stations within Basin Head lagoon and Antigonish Harbour. However, the accumulation of organisms at these two sites was not as high as that found near the outfall in Scoudouc fish plant. Increased local abundance may indicate an impacted area or it could also indicate good nursery habitat and/or an area with relatively healthy eelgrass known to support high abundance of animals (Orth and Heck Jr 1980; Orth et al. 1984; Sogard and Able 1991). For example, in Basin Head lagoon, station 1 had approximately 50% more animals than stations 2, 3, 6 and 7 which were all located on the eastern side of the lagoon. Station 1 was characterized by healthy eelgrass beds in each sampling month. Many young of the year fish such as sticklebacks, cunner and silverside were present at station 1 in August and September, possibly indicating a nursery area. Furthermore, station 1 was located near the boat launching ramp which could also affect the fish community by increasing habitat complexity. A study done in the Kouchibouguac National Park suggested there were some impacts on fish communities living near dock sites. Numbers of sticklebacks and striped bass appeared to be positively correlated with the presence of a dock (Bremner 2004). A combination of healthy eelgrass and the presence of a boat launch possibly created a relatively stable habitat and shelter from predation might have contributed to the increase in abundance at station 1.

The beach seine survey also found that station 4 in Antigonish, located at the mouth of the harbour, and station 6, located on Fallis Island, had higher species richness (10-12 species every month) than stations 1, 3, 5 (6-7 species every month). Rarer species such as pipefish, windowpane flounder, American sand lance, cunner and mud crab were usually found at stations 4 and 6 where no anthropogenic disturbance was observed.

Inter- and intra-estuarine temporal differences were also observed in our study. Multivariate analyses showed clear seasonal differences among the four months sampled when the four sites were pooled and also when each site was analyzed separately. Greatest differences were usually observed between the beginning of the season (i.e., July and August = summer) and the end of the season (i.e., September and October = fall). The high temporal variability in our study could explain why no spatial differences were found in the community structure within each site in the multivariate analyses. Numerous studies have shown that large spatial and temporal variation is a natural part of fish community structure in estuaries (Gray et al. 1996; Otway et al. 1996b). Large fluctuations in abundance can greatly affect the power of statistical tests, often increasing the chance of type II error (i.e., concluding that an impact has not occurred when it has). However, the power of the multivariate tests cannot easily be examined because they make no distributional assumptions. The only way to improve the power of the multivariate test is to increase replication (Clarke and Warwick 2001).

Univariate statistics were less sensitive in finding temporal differences within sites than multivariate statistics. Only Lamèque showed higher abundance in August and September compared to July and October. The relative paucity of fish found in October may be related to the low temperatures recorded during that month ranging from 5.23°C to 6.93°C. Major peaks of abundance often correlate with high temperature (MacDonald et al. 1984; Rountree and Able 1992; Lazzari et al. 1999). More fauna are usually present in the summer than fall because some animals, such as the Atlantic silverside (Conover and Murawski 1982), move offshore before winter to avoid low temperatures in shallow inshore waters. In our case, July showed high temperature (i.e., 19.84°C) but had a significantly lower number of adult fish than August and October. Significantly more YOY fish were present in September than July and August explaining in part the lower abundance in July. We only began discriminating YOY and adults in our counts in September, but a few

obvious juvenile fish were identified in July and August with fewer YOY detected in July than August. The mean species richness in Lamèque Bay was also higher in July (i.e., 5.5 species per beach seine haul) compared to August (4.3 species) and October (3.8 species), consistent with an exodus of spawning species in fall.

PATTERNS OF RICHNESS AND ABUNDANCE

Species richness and abundance in the four estuaries sampled were consistent with the pattern of numerical dominance by a few species in a relatively depauperate nearshore community that others have reported for estuaries of the sGSL (Joseph-Haché 2001; Robinson et al. 2001; Sharp et al. 2003; Bremner 2004). For example, Robinson et al. (2001) surveyed the nearshore fish community in Kouchibouguac and Richibucto Rivers with a beach seine and found a total of 22 fish taxa compared to 17 fish taxa in our study, 14 of which were common to both studies. Bremner (2004) surveyed the three largest estuaries and associated lagoons in the Kouchibouguac National Park (KNP) with a beach seine and found a total of 22 fish species including 14 species found in our study. Sharp et al. (2003) surveyed the nearshore fish community in Basin Head with a beach seine on September 2002 at the same seven stations surveyed in our study and found 10 fish species with the mummichog and the fourspine stickleback being the dominant species. Ten fish species were also caught in September 2003 in our study, eight of which were common to Sharp's study with the same two dominant species. Twelve fish species found in these other studies were not caught in our study because most of them were freshwater fish. Differences among studies could be related to different salinity ranges, time of sampling or sampling effort. Differences could also be attributed to sampling in areas devoid of eelgrass or within the mouths of inflowing watercourses. However, the taxa which were dominant in these surveys were similar to our study, thus indicating similar dominance across all estuaries of the sGSL. Finally, dominance by a few species is typical of many other fish community studies in shallow waters of the north eastern Atlantic coast. The dominant species consist predominantly of mummichog and Atlantic silverside as well as sticklebacks. When crustaceans are considered, sand shrimp and grass shrimp are also dominant (Targett and McCleave 1974; MacDonald et al. 1984; Ayvazian et al. 1992; Rountree and Able 1992; Lazzari et al. 1999; Robinson et al. 2001; Bremner 2004).

RELATING COMMUNITY STRUCTURE TO ENVIRONMENTAL DESCRIPTORS

Estuarine communities have been shown to correlate with many environmental factors, in particular temperature and salinity (Rountree and Able 1992; Locke and Courtenay 1995; Szedlmayer and Able 1996; Marshall and Elliott 1998; Lazzari et al. 1999; Able et al. 2001). Temperature and salinity were also strongly correlated with community structure in our study. When pooling all four sites together, temperature in combination with the % algae coverage correlated most strongly with community structure. Temperature also correlated with community assemblage at three of the four sites (i.e., Lamèque Bay, Scoudouc River estuary, Basin Head lagoon) suggesting a strong seasonal pattern in community structure. Seasonal patterns in abundance within estuaries have been attributed to seasonal shifts in faunal composition, spawning movements, recruitment of YOY and overwintering migration (Rountree and Able 1992, Marshall and Elliott 1998).

The SIMPER analyses revealed shifts in faunal composition and the species contributing the most to seasonal differences. Sand shrimp, mummichog and Atlantic silverside were common to all four sites as discriminating species between summer and fall (Table 4). Adult silverside, mummichog and threespine stickleback were usually more abundant in the summer than in the fall and sand shrimp and fourspine stickleback were abundant in both seasons. Young-of-the-year mummichog, YOY silverside and grass shrimp were always more abundant in the fall than in the summer although this distinction between YOY and adult only started in September.

Spearman rank correlation also demonstrated that temperature correlated with abundance of many individual species. For example, in Lamèque Bay temperature correlated positively with overall faunal abundance as well as with abundance of adult threespine stickleback, mummichog and silverside.

In Antigonish Harbour, when performing the BIOENV analyses, DO, salinity and % organic content were the best combination of abiotic variables describing the community structure at 27.5%. Antigonish was the only site in which salinity differed significantly among the stations. The stations closer to the harbour mouth (i.e., station 1, 2, 3, 4) all had significantly higher salinity possibly explaining why salinity was associated with the

community assemblage. Secondly, the dissolved oxygen in Antigonish varied broadly from 3.4 - 11.3 mg/L and was positively correlated with total abundance of fauna.

In Basin Head, the BIOENV analyses found that the % sea lettuce, temperature and MGS were the best abiotic combination correlating with the community assemblage at 40.7%. Of these three environmental variables, the % coverage by sea lettuce correlated most strongly. Spearman rank correlation also reflected the association between algae coverage and abundance of particular species, including a positive correlation with numbers of adult fourspine stickleback, threespine stickleback, adult mummichog and green crab. Greater abundance of fish in vegetated lagoons, estuaries, bays and marsh creeks compared to bare sandy areas has been well documented (Orth and Heck Jr. 1980; Sogard and Able 1991; Joseph-Haché 2001).

Finally, BIOENV analyses identified the most important environmental variables with regard to abiotic-biotic interactions. It also indicated that the environmental variables did not account for all of the observed variation in the community and population structure. It is likely that other biological interactions such as predator-prey relationships and prey distributions affect the fish and crustacean distribution patterns. Such biological interactions could be added to physico-chemical factors to better understand the community structure.

SEAFOOD PROCESSING PLANT EFFECTS

This study was designed to describe the fish and crustacean community of four estuaries in the sGSL, two of which had a seafood processing plant located on their shores. It is one of the first studies to examine whether the abundance and composition of fish and crustacean communities are affected by waste effluent from seafood processing plants. For this section, we looked at intra-site differences in Lamèque Bay and Scoudouc River estuary since these were the only two sites with a processing plant nearby and inter-site differences were discussed in the earlier sections.

Our study showed increased numbers of fish near one of the two fish plants (Scoudouc River estuary). This higher abundance of fish was localized (i.e., tens of meters) and was comprised of a few species such as the silverside, threespine and fourspine stickleback. We hypothesize that these species might be attracted to the effluent as a source

of food, since effluent is characterized by high levels of organic suspended solids (Wells and Schneider 1975; NovaTec Consultants Inc and EVS Consultants 1994; AMEC Earth & Environmental Limited 2003; Morry et al. 2003; Tchoukanova et al. 2003). Our results are similar to those of other studies near sewage outfalls which also found increased abundance of certain fish species (Bell and Harmelin-Vivien 1982; Grigg 1994; Otway et al. 1996b).

Conversely, Lamèque Bay did not show a higher abundance of fish near the outfall. Several factors might explain the difference between Scoudouc River estuary and Lamèque Bay. First, the closest station that we could access with the beach seine was approximately 420 m away from the outfall in Lamèque, possibly too far away to reflect the kind of localized effect seen in Scoudouc River estuary. The processing plants in Scoudouc River estuary and Lamèque Bay process different products (lobster vs. a variety of finfish and shellfish) and have very different effluent volumes and characteristics which could also contribute to the different response between these two sites. The inability to detect significant spatial differences in Lamèque could also be related to the high monthly fluctuation in abundance. For example, a period of hypoxia ($DO = 0.2$ mg/L) at station 7 was associated with low fish abundance in July at which time only one mummichog was captured. The hypoxia event occurred during strong onshore winds causing resuspension of organic laden-sediments and entrainment of fish plant effluent onshore. This suggests that fish and crustaceans tend to move away from an area that has become hypoxic. However, our catches the next month (total abundance = 602) at that same station indicated that the fauna returned fairly quickly. This is good evidence of how variable environmental conditions and faunal distributions can be within an estuary from month to month and likely contributed to the high variability of replicates which may explain our incapacity to detect spatial differences. It also implies that littoral communities reflect at least large changes in environmental health in estuaries of the sGSL.

The results seen in Scoudouc River estuary and Lamèque Bay in 2003 led us to concentrate our sampling efforts in 2004 on fish processing plants having outfalls accessible with a beach seine, that discharge into similar receiving environments, and that process similar products. It was hypothesized that fish sampled under such conditions might show effects on survival (i.e., reflected in age), energy storage (i.e., condition factors, livensomatic factor) or energy allocation (i.e., gonadosomatic index and growth). To test

this hypothesis, we added a second monitoring approach in 2004 to test the environmental effect of effluent from seafood processing plants using the sentinel species approach of the Canadian Environmental Effects Monitoring (EEM) program for pulp and paper mills (Environment Canada 2005). From our 2003 sampling, we were able to select the mummichog and the Atlantic silverside as sentinel species. These two species were two of the most abundant and ubiquitous species in our study, both within and outside the perceived influence of seafood processing effluent.

RESEARCH RECOMMENDATIONS

- Continue working with local community groups to build a time series of baseline data for long term monitoring through CAMP.
- Consider instituting a Quality Assurance/Quality Control (QA/QC) program to quantify the accuracy and precision of identifications and abundance estimates of fish, crustaceans, aquatic macrophytes, algae and environmental variables.
- Consider integrating other programs with CAMP such as the CABIN (Community Aquatic Benthic Invertebrate Network) that has similar objectives to CAMP. Other programs could also quantify invasive species found in sites being sampled by CAMP.
- Consider counting the total abundance of animals captured with our beach seine and use an estimate method to approximate the very large catches. Curtailing our count to 300 was recognized to be suboptimal and was corrected for the seafood effluent environmental impact study.
- Consider collecting more than one sediment replicate per station to determine whether a single sample adequately characterizes the area. Sediment sampling can be restricted to the first and last month of sampling when differences in organic and moisture content are likely to be maximal.
- The sampling season for CAMP and for the evaluation of seafood processing plant effects should start earlier than the present study (e.g., May) to include all seasonal variability that can reasonably be sampled. Sampling can end in September because the present study indicated that after this period some species move offshore for overwintering. For many seafood processing plants, May-September sampling will also include the period of peak production and potential for environmental impact. After

several years of data collection, analyses can be conducted to determine whether sampling needs to occur in all 5 months or whether relevant information can be collected with less effort.

- Reducing the number of sampling stations to a maximum of 6 stations per site which will allow sampling of a site in a single day. These makes sense for characterizing sites through CAMP in 2004 and will facilitate the sampling for the community groups. On the other hand, testing hypotheses concerning effects of particular point sources within a site, such as a fish plant, will benefit from synoptic sampling of more stations, and possibly repeat sampling of stations after 1 or several days, to increase power while minimizing temporal variance.
- Focus the evaluation of seafood processing plant effluent effect on plants carrying out similar processing and discharging into similar environments. As a first step, build on the results of this study by sampling Scoudouc and two other plants processing lobsters and/or crab and discharging into small, estuarine environments of sGSL. Select plants at which the end of pipe is easily accessible with a beach seine.
- For the seafood processing effluent study, supplement the community data with data on sublethal effects in abundant species. Add the mummichog and the Atlantic silverside as sentinel species to evaluate the effect of seafood waste effluent on growth, reproduction and survival following the guidelines of the Pulp and Paper Effluent Regulations Environmental Effect Monitoring (EEM) (Environment Canada 2005).

CONCLUSION

The fish and crustacean assemblages of the four sites sampled consisted of a total of 22 species and were dominated by 6 species. This pattern of relatively low species number, coupled with the high abundance of a few species is typical for temperate estuarine environments.

Effluent from a fish processing plant was associated with a change in the near field community structure in Scoudouc River estuary by having large numbers of silverside and fourspine stickleback aggregating near the outfall. Our study lacks sufficient data to identify the mechanism and causality for this increased abundance but we hypothesize that fish are attracted to the plume as a source of food. Species-specific diet, habitat preferences

and interspecific competition might explain why only certain species aggregate in the plume. Conversely, low species richness and abundance in Lamèque Bay may be due, at least in part, to the high nutrient input from that fish plant, ultimately reducing habitat quality and resulting in a negative impact. Further research on the receiving environment needs to be pursued to fully understand the impact of fish plant effluent and to develop an Environmental Effects Monitoring (EEM) program. Supplementing the community study approach with a study of growth, survival and reproduction in selected sentinel species will provide much of the needed information.

The CAMP showed clear seasonal differences in the fish and crustacean community of sGSL estuaries which suggests that additional research will be required to establish optimal timing and frequency of sampling. Finally, the CAMP provided a good indication of the abundance and diversity of species present in bays and estuaries in the sGSL and efforts should be focused on long term monitoring with the ultimate goal of identifying changes from baseline conditions and directing attention towards particular sites or stations.

ACKNOWLEDGEMENTS

We wish to thank the Department of Fisheries and Oceans (DFO), the University of Moncton and the Southern Gulf of St. Lawrence Coalition on Sustainability for their financial support towards this study. This work would not have been possible without the staff at the DFO regional offices: Ernest Ferguson and Anne Turcotte in Tracadie, NB, Delephina Keen and Ray MacIsaac in Charlottetown PEI, Danielle Goff and Paul Boyd in Antigonish NS. We would also like to thank the community groups that sampled in the field including: the Shediac Bay Watershed Association, la Coalition pour la viabilité de l'environnement des havres de Shippagan et les Îles Miscou et Lamèque, Fresh Air Outdoor Adventure Society-Antigonish, students from the St. Francis Xavier University Biology Department and the Basin Head Lagoon Ecosystem Conservation Committee. Thanks to Monica Boudreau and the co-op students that helped in the field as well as in the laboratory.

REFERENCES

- Able, K. W., D. M. Nemerson, R. Bush, and P. Light. 2001. Spatial variation in Delaware bay (U.S.A.) marsh creek fish assemblages. *Estuaries* 24:441-452.
- Adams, S. M., K. D. Ham, M. S. Greeley, R. F. LeHew, D. E. Hinton, and C. F. Saylor. 1996. Downstream gradients in bioindicator responses: point source contaminant effects on fish health. *Canadian Journal of Fisheries and Aquatic Sciences* 53:2177-2187.
- AMEC Earth & Environmental Limited. 2003. Management of wastes from Atlantic seafood processing operations. Submitted to National Programme of Action Atlantic Regional Team. Report number. TE-23016.
- Ayvazian, G. S., L. A. Deegan, and J. T. Finn. 1992. Comparison of habitat use by estuarine fish assemblages in the Acadian and Virginian zoogeographic provinces. *Estuaries* 15:368-383.
- Bell, J. D. and M-L. Harmelin-Vivien. 1982. Fish fauna of French Mediterranean *Posidonia oceanica* seagrass meadows. 1. Community structure. *Tethys* 10:337-347.
- Bremner, A. M. 2004. Variation in estuarine fish communities in Kouchibouguac National Park with special reference to potential impact by commercial and recreational docks. M.Sc. Thesis: University of New Brunswick. 104pp.
- Cao, Y., D. P. Larsen, and R. St-J. Thorne. 2001. Rare species in multivariate analysis for bioassessment: some considerations. *Journal of North American Benthic Society* 20:144-153.
- Clarke, K. R. and M. Ainsworth. 1993. A method of linking multivariate community structure to environmental variables. *Marine Ecology Progress Series* 92:205-219.
- Clarke, K. R. and R. N. Gorley. 2001. PRIMER v5: User Manual/Tutorial. PRIMER-E: Plymouth Ltd. West Hoe, W.K. 91pp.
- Clarke, K. R. and R. M. Warkick. 2001. Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER-E: Plymouth. 144pp.
- Conover, D. O. and S. A. Murawski. 1982. Offshore winter migration of the Atlantic silverside, *Menidia menidia*. *Fisheries Bulletin* 80:145-150.
- deBruyn, A. M. H., D. J. Marcogliese, and J. B. Rasmussen. 2002. Altered body size distributions in a large river fish community enriched by sewage. *Canadian Journal of Fisheries and Aquatic Science* 59:819-828.

- Douglas, S. G., R. G. Bradford and G. Chaput. 2003. Assessment of striped bass (*Morone saxatilis*) in the maritime provinces in the context of species at risk. Canadian Science Advisory Secretariat research document. 2003/008.
- Environment Canada. 1975. Fish Processing Operations Liquid Effluent Guidelines. Environmental Protection Service, Water Pollution Control Directorate. Report No. EPS 1-WP-75-1.
- Environment Canada. 2005. Pulp and paper technical guidance document. [On line]. Available at: <http://www.ec.gc.ca/eem/English/PulpPaper/Guidance/default.cfm>
- Fausch, K. D., J. R. Karr, and P. R. Yant. 1984. Regional application of an index of biotic integrity based on stream fish communities. Transactions of the American Fisheries Society 113:39-55.
- Gray, C. A., D. J. McElligott, and R. C. Chick. 1996. Intra- and inter- estuary differences in assemblages of fishes associated with shallow seagrass and bare sand. Marine and Freshwater Research 47:723-735.
- Griffiths, S. P. 2001. Diel variation in the seagrass ichthyofaunas of three intermittently open estuaries in south-eastern Australia: implications for improving fish diversity assessments. Fisheries Management and Ecology 8:123-140.
- Grigg, R. W. 1994. Effects of sewage discharge, fishing pressure and habitat complexity on coral ecosystems and reef fishes in Hawaii. Marine Ecology Progress Series 103:25-34.
- Higgins, R. P. and H. Thiel. 1988. Introduction to the study of meiofauna. Smithsonian Institution Press, Washington, D.C. London. 488pp.
- Hughes, J. E., L. A. Deegan, J. C. Wyda, and M. J. Weaver. 2002. The effects of eelgrass habitat loss on estuarine fish communities of southern New England. Estuaries: 25: 235-249.
- Island Nature Trust. 2001. Community use of the Basin Head Lagoon, Prince Edward Island. Report prepared by the Island Nature Trust for the Basin Head Lagoon Ecosystem Conservation Committee. 26p.
- Joseph-Haché, V. 2001. Spatial and temporal distribution of fishes and decapods in and around eelgrass (*Zostera marina* L.) habitats of Kouchibouguac estuary, New Brunswick, Canada. M.Sc. Thesis: Mount Allison University. 187pp.
- Karr, J. R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6:21-27.
- Karr, J. R. 1987. Biological monitoring and environmental assessment: a conceptual framework. Environmental Management 11:249-256.

- Lazzari, M. A., S. Sherman, C. S. Brown, J. King, B. J. Joule, S. B. Chenoweth, and R. W. Langton. 1999. Seasonal and annual variation in abundance and species composition of two nearshore fish communities in Maine. *Estuaries* 22:636-647.
- Locke, A. and S. C. Courtenay. 1995. Effects of environmental factors on ichthyoplankton communities in the Miramichi estuary, Gulf of St Lawrence. *Journal of Plankton Research* 17:333-349.
- Lotze, H. K., I. Milewski, B. Worm and Z. Koller. 2003. Nutrient Pollution: A eutrophication survey of eelgrass beds in estuaries and coastal bays in northern and eastern New Brunswick. Concervation Council of New Brunswick Inc. 60pp.
- Lowell, R. B., S. C. Ribey, I. K. Ellis, E. L. Porter, J. M. Culp, L. C. Grapentine, M. E. McMaster, K. R. Munkittrick, and R. P. Scroggins. 2003. National assessment of the pulp and paper environmental effects monitoring data. NWRI contribution. No. 03-521. 124pp.
- MacDonald, J. S., M. J. Dadswell, R. G. Appy, G. D. Melvin, and D. A. Methven. 1984. Fishes, fish assemblages, and their seasonal movements in the lower bay of Fundy and Passamaquoddy Bay, Canada. *Fisheries Bulletin* 82:121-139.
- Marshall, S. and M. Elliott. 1998. Environmental influences on the fish assemblage of the Humber estuary, U.K. *Estuarine, Coastal and Shelf Science* 46:175-184.
- Methven, D. A., R. L. Haedrich, and G. A. Rose. 2001. The fish assemblage of a Newfoundland estuary: Diel, monthly and annual variation. *Estuarine, Coastal and Shelf Science* 52:669-687.
- Methven, D. A. and D. C. Schneider. 1998. Gear-independent patterns of variation in catch of juvenile Atlantic cod (*Gadus morhua*) in coastal habitats. *Canadian Journal of Fisheries and Aquatic Sciences* 55:1430-1442.
- Ministry of Business New Brunswick. 2003. Index of Transformation Business in 2003. Access on line at : <http://www.gnb.ca/0168/aquatic.pdf> (Accessed July 2003).
- Minns, C. K., V. W. Cairns, R. G. Randall, and J. E. Moore. 1994. An index of biotic integrity (IBI) for fish assemblages in the littoral zone of Great Lakes areas of concern. *Canadian Journal of Fisheries and Aquatic Sciences* 51:1804-1822.
- Morry, C. J., M. Chadwick, S. C. Courtenay, and P. Mallet. 2003. Fish plant effluents: A workshop on sustainability. Canadian Industry Report of Fisheries and Aquatic Sciences No.271. 106pp.
- Neuman, E. and P. Karás. 1988. Effects of pulp mill effluent on a Baltic coastal fish community. *Water Science and Technology* 20:95-106.

- NovaTec Consultants Inc. and EVS Consultants. 1994. Fraser River Action Plan: Wastewater characterization of fish processing plant effluents. Technical Report Series. FREMP. WQWM 93-10. DOE FRAP 1993-39.
- Orth, R. J. and K. L. Heck Jr. 1980. Structural components of eelgrass (*Zostera marina*) meadows in the lower Chesapeake Bay – Fishes. *Estuaries* 3:278-288.
- Orth, R. J., K. L. Heck Jr. and van Montfrans J. 1984. Faunal communities in seagrass beds: A review of the influence of plant structure and prey characteristics on predator-prey relationship. *Estuaries* 7:339-350.
- Otway, N. M., C. A. Gray, J. R. Craig, T. A. McVea, and J. E. Ling. 1996a. Assessing the impacts of deepwater sewage outfalls on spatially- and temporally-variable marine communities. *Marine Environmental Research* 41:45-71.
- Otway, N. M., D. J. Sullings, and N. W. Lenehan. 1996b. Trophically-based assessment of the impacts of deepwater sewage disposal on a demersal fish community. *Environmental Biology of Fishes* 46:167-183.
- Robichaud-LeBlanc, K. A., S. C. Courtenay and A. Locke. 1996. Spawning and early life history of a northern population of striped bass (*Morone saxatilis*) in the Miramichi River Estuary, Gulf of St. Lawrence. *Canadian Journal of Zoology* 74:1645-1655.
- Robinson, M., S. C. Courtenay, T. Benfey, and E. Tremblay. 2001. The fish community and use of the Kouchibouguac and Richibucto estuaries by striped bass during the spring and summer of 1997 and 1998. Parks Canada Technical Reports in Ecosystem Science. Report No. 032. 83pp.
- Rountree, R. A. and K. W. Able. 1992. Fauna of polyhaline subtidal marsh creeks in southern New Jersey: Composition, abundance and biomass. *Estuaries* 15:171-185.
- Roy Consultants Ltd., NATECH Environmental Services Inc. and OCL Group Environmental Management Consultants. 2003. Lamèque Bay environmental management study. Report No. 133-01.
- Sharp, G., R. Semple, K. Connolly, Martec Ltd., D. Audet, D. Cairns and S. Courtenay. 2003. Ecological assessment of the candidate marine protected area, Basin Head Lagoon. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2641: vii + 70p.
- Skinner, M.A., S.C. Courtenay, W. R. Parker and R.A. Currie. 2005. Site fidelity of mummichogs (*Fundulus heteroclitus*) in an Atlantic Canadian estuary. *Water Quality Research Journal of Canada* 40(3): 288-298.
- Sogard, S. M. and K. M. Able. 1991. A comparison of eelgrass, sea lettuce macroalgae, and marsh creeks as habitats for epibenthic fishes and decapods. *Estuaries, Coastal and Shelf Science* 33:501-519.

- Szedlmayer, S. T. and K. M. Able. 1996. Patterns of seasonal availability and habitat use by fishes and decapod crustaceans in a southern New Jersey estuary. *Estuaries* 19:697-709.
- Targett, T. E. and J. D. McCleave. 1974. Summer abundance of fishes in a Maine tidal cove with special reference to temperature. *Transaction of American Fisheries Society* 2:325-330.
- Tchoukanova N., M. Gonzalez, and S. Poirier. 2003. Best Management Practices: Marine Products Processing. Fisheries and Marine Products Division of the Coastal Zones Research Institute Inc., Shippagan, New Brunswick, Canada. 38p.
- Wells, P. G. and J. R. Schneider. 1975. Characteristics of fish plant wastes in Nova Scotia and their effects on coastal bays III: Toxicity studies. Toxicity Evaluation Section. Environmental Service Branch. Environmental Protection Service Atlantic Region. EPS-8-AR-75-4. 22pp.
- Whitfield, A. K. and M. Elliott. 2002. Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. *Journal of Fish Biology* 61(Supplement A):229-250.

Table 1. Total abundance of each species (young-of-the-year (YOY) and adult) caught in Lamèque Bay, Scoudouc River estuary, Antigonish Harbour and Basin Head lagoon between July and October, 2003.

Common /scientific name	Sites								total
	Lamèque Bay		Scoudouc R. estuary		Antigonish H.		Basin Head L.		
	YOY	adult	YOY	adult	YOY	adult	YOY	adult	
Blackspotted stickleback*** <i>Gasterosteus wheatlandi</i>	--	67	--	164	--	5	2	26	264
Threespine stickleback*** <i>Gasterosteus aculeatus</i>	4	80	277	1327*	4	31	14	574	2311
Fourspine stickleback <i>Apeltes quadracus</i>	4	231	70	801	285	647*	750*	2382*	5170
Ninespine stickleback <i>Pungitius pungitius</i>	--	6	--	4	41	324	1	204	580
Mummichog*** <i>Fundulus heteroclitus</i>	1791*	1930*	2053*	2340*	2389*	2494*	617*	1697*	15311
Banded killifish*** <i>Fundulus diaphanus</i>	--	--	1	77	101	362	--	--	541
Atlantic silverside <i>Menidia menidia</i>	1667*	4220*	993*	1716*	492	1850*	149	553*	11640
Cunner <i>Tautogolabrus adspersus</i>	--	--	2	--	4	--	18	--	24
Alewife*** <i>Alosa spp</i> ***	18	--	12	--	2	--	--	--	32
Striped bass <i>Morone saxatilis</i>	12	--	--	--	--	--	--	--	12
White hake <i>Urophycis tenuis</i>	--	--	--	--	--	--	1	--	1
American eel <i>Anguilla rostrata</i>	--	--	--	--	--	1	--	--	1
American sand lance <i>Ammodytes americanus</i>	--	--	--	--	1	3	--	--	4
Northern pipefish <i>Syngnathus fuscus</i>	--	--	--	--	6	28	4	12	50
Windowpane <i>Scophthalmus aquosus</i>	--	--	--	--	9	--	--	--	9
Flounder sp.*** <i>Pleuronectes spp.</i> ***	6	--	17	--	1	--	6	--	30
Smooth flounder <i>Pleuronectes putnami</i>	19	--	50	1	7	1	30	0	121
Winter flounder <i>Pseudopleuronectes americanus</i>	13	--	5	6	34	30	137	10	235
Fish total	10068		9916		9152		7200		36336

Table 1. (Continued)

	Sites								
	Lamèque Bay		Scoudouc R. estuary		Antigonish H.		Basin Head L.		
Common / scientific name	YOY	adult	YOY	adult	YOY	adult	YOY	adult	total
Grass shrimp <i>Palaemonetes vulgaris</i>		2		769		212		47	1030
Sand shrimp <i>Crangon septemspinosa</i>		1801*		546		4442*		5485*	12274
Rock crab <i>Cancer irroratus</i>	--	2	--	2	1	--	25	62	92
Green crab <i>Carcinus maenas</i>	--	--	--	--	41	309	13	233	596
Mud crab Xanthidae family	--	--	1	--	--	1	--	--	2
Crustacean total		1805		1318		5006		5865	13994
Total (fish + crustacean)		11873		11234		14158		13065	50330
Beach seine hauls		40		26		27		25	118
CPUE**fish		252*		381*		339*		288*	
CPUE**crustacean		45*		51		185*		235*	
CPUE** total		297*		432*		524*		523*	

* Totals are minima because counts of very abundant species were capped at 300.

** CPUE = catch per unit effort

*** The identification between the blackspotted stickleback and the threespine stickleback; between the mummichog and the banded killifish; between the smooth and the winter flounder; between the two clupeidae species - blueback herring (*Alosa aestivalis*) and the alewife were difficult and less accurate for these species at the juvenile stage.

Table 2. Results of the two-way analysis of similarity (ANOSIM) comparison for the fish and crustacean community among the different sites (i.e., Lamèque Bay, Scoudouc River estuary, Basin Head lagoon and Antigonish Harbour) and the different months (i.e., July to October) in 2003. Values obtained by the ANOSIM are Global R statistic and the pairwise comparison R statistic. Significant levels are in parentheses.

Variables	Global R statistics (significant level)	
<i>Sites</i>	0.428	(<0.001)*
Pairwise comparison		
Lamèque vs. Scoudouc R. estuary	0.393	(<0.001)*
Lamèque vs. Antigonish	0.382	(<0.001)*
Lamèque vs. Basin Head	0.593	(<0.001)**
Scoudouc R. estuary vs. Antigonish	0.373	(<0.001)*
Scoudouc R. estuary vs. Basin Head	0.578	(<0.001)**
Antigonish vs. Basin Head	0.284	(<0.001)*
<i>Months</i>	0.490	(<0.001)*
Pairwise comparison		
July vs. August	0.408	(<0.001)*
July vs. September	0.653	(<0.001)**
July vs. October	0.543	(<0.001)**
August vs. September	0.398	(<0.001)*
August vs. October	0.669	(<0.001)**
September vs. October	0.327	(<0.001)*

*** $R \geq 0.75$ = well separated, ** $0.75 > R \geq 0.5$ = overlapping but different, * $0.5 > R \geq 0.25$ = overlapping but somewhat different, $R < 0.25$ = insufficiently different (Clarke and Gorley 2001).

Table 3. Analysis of similarity (one-way ANOSIM) for the fish and crustacean community for each site individually among the stations (months being pooled as replicates) and among the months (station being pooled as replicates). Values obtained by ANOSIM are Global R statistic and the pairwise comparison R statistic. Significant levels are in parentheses.

Variables	Global R statistics (significant level)	
Lamèque Bay Station (1 to 10)	-0.113	(0.966) n.s.
Months (July to October)	0.581	(<0.001)**
Pairwise comparison		
July vs. August	0.533	(<0.001)**
July vs. September	0.654	(<0.001)**
July vs. October	0.518	(<0.001)**
August vs. September	0.349	(<0.001)*
August vs. October	0.894	(<0.001)***
September vs. October	0.621	(<0.001)**
Scoudouc R. estuary Station (1 to 7)	0.156	(0.06) n.s.
Months (July to October)	0.489	(<0.001)**
Pairwise comparison		
July vs. August	0.200	(0.093) n.s.
July vs. September	0.856	(0.001)***
July vs. October	0.545	(0.004)**
August vs. September	0.534	(0.001)**
August vs. October	0.605	(0.001)**
September vs. October	0.180	(0.041) n.s.
Antigonish Harbour Station (1 to 7)	0.143	(0.054) n.s.
Months (July to October)	0.509	(<0.001)**
Pairwise comparison		
July vs. August	0.517	(0.002)**
July vs. September	0.786	(0.001)***
July vs. October	0.647	(0.001)**
August vs. September	0.647	(0.001)**
August vs. October	0.542	(0.001)**
September vs. October	0.008	(0.368) n.s.
Basin Head lagoon stations (1 to 7)	0.138	(0.069) n.s.
months (July to October)	0.253	(0.5)*
Pairwise comparison		
July vs. August	0.153	(0.098) n.s.
July vs. September	0.341	(0.08)*
July vs. October	0.483	(0.09)*
August vs. September	0.121	(0.105) n.s.
August vs. October	0.253	(0.048)*
September vs. October	0.073	(0.244) n.s.

*** $R \geq 0.75$ = well separated, ** $0.75 > R \geq 0.5$ = overlapping but different, * $0.5 > R \geq 0.25$ = overlapping but somewhat different, $R < 0.25$ = insufficiently different (Clarke and Gorley 2001).

n.s. = not significant

Table 4. SIMPER results indicating the top eight species contributing most to the average dissimilarity or the top species contributing up to 90% dissimilarity between summer and fall for all four sites.

Pairwise comparison	Average (avg) dissimilarity among seasons	Species	Summer avg. abundance	Fall avg. abundance	Avg. dissimilarity	Contributed % dissimilarity	Cumulative Contributed % dissimilarity
<i>All four sites</i>							
Summer vs. fall	66.44%	MUMI (A)	112.2	32.73	10.04	15.12	15.12
		SASP (A)	102.60	105.38	9.87	14.85	29.97
		MUMI (YOY)	10.34	104.17	8.91	13.41	43.39
		SILV (A)	88.48	53.45	7.67	11.55	54.93
		SILV (YOY)	0.12	54.90	6.44	9.69	64.63
		4SSB (A)	35.10	33.75	4.72	7.11	71.73
		3SSB (A)	25.91	8.48	3.56	5.36	77.09
		GRSP (A)	6.05	11.32	2.79	4.20	81.29
<i>Lamèque Bay</i>							
Summer vs. fall	68.79%	MUMI (A)	85.95	10.55	13.62	19.79	19.79
		SASP (A)	41.55	48.50	12.27	17.84	37.63
		SILV (A)	125	86.00	11.49	16.71	54.34
		SILV (YOY)	0.00	83.35	11.36	16.51	70.85
		MUMI (YOY)	30.00	59.55	9.08	13.20	84.05
		4SSB (A)	7.00	4.55	4.17	6.06	90.10
<i>Scoudouc R. estuary</i>							
Summer vs. fall	65.98%	MUMI (YOY)	0.00	146.64	12.42	18.82	18.82
		MUMI (A)	161.25	28.93	11.17	16.94	35.75
		SILV (YOY)	0.00	70.93	6.27	9.50	45.26
		SILV (A)	85.50	49.29	6.15	9.33	54.58
		3SSB (A)	72.33	32.79	5.67	8.59	63.18
Continued...table 4		SASP (A)	14.00	27.00	5.53	8.38	71.56

Antigonish Harbour

Antigonish Harbour						
Summer vs. fall		56.89%				
GRSP (A)	16.42	40.86	5.12	7.76	79.32	
4SSB (A)	34.75	27.43	4.00	6.06	85.37	
MUMI (YOY)	0.00	170.64	10.90	19.16	19.16	
MUMI (A)	121.92	64.93	7.97	14.02	33.18	
SASP (A)	166.23	162.93	7.48	13.15	46.33	
SILV (A)	109.23	30.71	6.68	11.74	58.08	
SILV (YOY)	0.54	34.64	4.50	7.90	65.98	
4SSB (A)	11.38	35.64	3.29	5.79	71.77	
GRCR (A)	19.46	4.00	3.22	5.66	77.43	
4SSB (YOY)	0.23	20.14	2.81	4.95	82.38	

Basin Head lagoon

Basin Head lagoon						
Summer vs. fall		49.67%				
SASP (A)	214.69	224.50	8.44	16.99	16.99	
MUMI (A)	96.77	36.58	7.06	14.21	31.20	
4SSB (A)	102.38	87.58	6.16	12.40	43.60	
4SSB (YOY)	0.00	62.50	5.13	10.33	53.93	
3SSB (A)	41.85	2.50	3.95	7.95	61.88	
MUMI (YOY)	0.00	51.42	3.45	6.95	68.84	
SILV (A)	14.31	30.58	3.43	6.91	75.74	
WTFL (YOY)	1.77	9.50	3.05	6.14	81.88	

A = adult, YOY = young-of-the-year. MUMI: mummichog; SASP: sand shrimp; SILV: Atlantic silverside; 4SSB: fourspine stickleback; 3SSB: threespine stickleback; GRSP: grass shrimp.

Table 5. Spatial and temporal differences in percent organic content, percent moisture content and Mean Grain Size (MGS) of surficial sediment samples for each site.

Dependant variable	Independent Variable	F	p	Tukey results
Lamèque Bay				
organic content	station	$F_{(9,25)} = 0.951$	0.501	October<July, June, Aug. 3,5,7>8 and 3>4,9
	month	$F_{(3,31)}=2.830$	0.055	
moisture content	station	$F_{(9,25)} = 1.140$	0.373	
	month	$F_{(3,31)} = 6.129$	0.002	
MGS	station	$F_{(9,24)} = 4.803$	0.001	
	month	$F_{(3,30)}=0.895$	0.455	
Plant coverage	station	$F_{(9,30)} = 2.054$	0.068	
	month	$F_{(6,19)} = 0.865$	0.468	
Algae coverage	station	$F_{(9,30)} = 0.850$	0.578	August > July
	month	$F_{(3,36)} = 3.309$	0.031	
Scoudouc R. Estuary				
organic content	station	$F_{(6,19)} = 1.067$	0.416	4>3 July > August
	month	$F_{(3,22)} = 0.289$	0.833	
moisture content	station	$F_{(6,19)} = 1.500$	0.231	
	month	$F_{(3,22)} = 1.588$	0.221	
MGS	station	$F_{(6,19)} = 2.734$	0.044	
	month	$F_{(3,22)} = 1.114$	0.365	
Plant coverage	station	$F_{(6,19)} = 0.473$	0.820	
	month	$F_{(3,22)} = 3.354$	0.037	
Algae coverage	station	$F_{(6,19)} = 1.632$	0.193	
	month	$F_{(3,22)} = 1.033$	0.397	
Basin Head lagoon				
organic content	station	$F_{(6,18)} = 3.176$	0.026	6> 2, 7
	month	$F^*_{(3,18)} = 6.405$	0.004	July<Sept. and Oct. ; Aug<Sept
moisture content	station	$F_{(6,18)} = 3.168$	0.027	
	month	$F_{(3,21)} = 1.158$	0.349	
MGS	station	$F_{(6,18)} = 16.568$	>0.001	2,6,7>1,3,4,5
	month	$F_{(3,21)} = 0.157$	0.924	1,6 > 4, 5
Plant coverage	station	$F_{(6,18)} = 5.353$	0.003	
	month	$F_{(3,21)} = 2.028$	0.141	2 < 5* (Tukey test p = 0.051)
Algae coverage	station	$F_{(6,18)} = 2.893$	0.037	
	month	$F_{(3,21)} = 1.084$	0.377	

Continued....Table 5

Antigonish Harbor	Independent Variables	F	p	Tukey results
organic content	station	$F_{(6,16)} = 4.140$	0.011	1>3,4,6,7
	month	$F_{(3,22)} = 1.077$	0.379	
moisture content	station	$F_{(6,19)} = 2.101$	0.101	
	month	$F_{(3,22)} = 1.036$	0.396	
MGS	station	$F_{(6,20)} = 3.667$	0.013	6,7>1
	month	$F_{(3,23)} = 0.333$	0.802	
Plant coverage	station	$F_{(6,20)} = 3.262$	0.021	Tukey did not find which station differed
	month	$F_{(3,23)} = 0.976$	0.421	
Algae coverage	station	$F_{(6,20)} = 3.649$	0.013	7 > 1,2,4,6
	month	$F_{(3,23)} = 0.595$	0.625	

* Without the outliers

Table 6. BIOENV results giving the combination of environmental variables yielding the best match between the biotic and abiotic similarity matrices for each month in Lamèque Bay and Scoudouc River estuary. Values in brackets are Spearman weighted rank correlation coefficients (ρ_w) for each environmental variable taken singly. The Global ρ_w is the global value for the best combination of environmental variables. Distance refers to distance from the outfall of a fish processing plant.

Site	Month	Best variable combination (individual ρ_w)	Global ρ_w
Lamèque Bay	July	Distance (0.386), DO (0.149)	0.505
	August	Temperature (0.309)	0.309
	September	% Eelgrass coverage (0.600)	0.600
	October	% Eelgrass coverage (0.413)	0.413
Scoudouc R. estuary	July	Temperature (0.337), MGS (0.007), % algae coverage (-0.127)	0.784
	August	Distance (0.410), DO (0.013), salinity (-0.134)	0.468
	September	% organic content (0.305), salinity (0.260), MGS (-0.094)	0.487
	October	Distance (0.254)	0.254

Table 7. Lamèque Bay Spearman rank correlation results between the dominant species, the species richness, the total abundance of animals and different environmental factors.

Species	Temperature	Salinity	DO	Organic content	Moisture content	MGS	Eelgrass coverage	Algae coverage	proximity to FP
Sp. richness	ns	--	ns	ns	ns	ns	ns	ns	ns
Abundance	+	ns	ns	ns	ns	ns	ns	ns	ns
4SSB (A)	ns	-	---	ns	ns	ns	ns	ns	ns
3SSB (A)	+	--	ns	ns	ns	ns	ns	ns	ns
MUMI (YOY)	ns	ns	ns	ns	ns	ns	ns	ns	ns
MUMI (A)	++	--	-	ns	ns	ns	ns	ns	ns
SILV (YOY)	---	-	ns	ns	ns	ns	ns	ns	ns
SILV (A)	++	ns	ns	ns	ns	ns	ns	ns	ns
SASP (A)	ns	ns	ns	ns	ns	ns	ns	ns	ns
GRSP (A)	ns	ns	ns	ns	ns	ns	ns	ns	ns
WTFL (TOT)	ns	ns	ns	ns	ns	ns	ns	ns	ns
SMFL (TOT)	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns (not significant), $p > 0.05$; + or -, $0.05 \geq p > 0.01$; ++ or --, $0.01 \geq p > 0.001$; +++ or ---, $p \leq 0.001$

A = adult; YOY = young-of-the-year; TOT = total adult and juvenile; MGS = mean grain size; DO = dissolved oxygen in water; FP = fish plant effluent outfall; 4SSB = fourspine stickleback; 3SSB = threespine stickleback; MUMI = mummichog; SILV = Atlantic silverside; SASP = sand shrimp; GRSP = grass shrimp; WTFL = winter flounder; SMFL = smooth flounder

Table 8. Scoudouc River estuary Spearman rank correlation results between the most dominant species, the species richness, the total abundance of animals and different environmental factors.

Species	Temperature	Salinity	DO	Organic content	Moisture content	MGS	Eelgrass coverage	Algae coverage	Proximity to FP
Sp. richness	ns	ns	ns	ns	ns	ns	ns	ns	ns
Abundance	ns	ns	ns	ns	ns	ns	ns	ns	ns
4SSB (A)	ns	ns	ns	ns	ns	ns	ns	ns	ns
3SSB (A)	ns	ns	ns	ns	ns	ns	ns	ns	+
MUMI (YOY)	---	++	ns	ns	ns	ns	ns	ns	ns
MUMI (A)	++	-	ns	ns	ns	ns	ns	ns	ns
SILV (YOY)	---	+	ns	ns	ns	ns	ns	ns	ns
SILV (A)	ns	ns	ns	ns	ns	ns	ns	ns	+
SASP (A)	ns	+	ns	ns	ns	ns	ns	ns	ns
GRSP (A)	ns	ns	ns	ns	ns	ns	ns	ns	ns*
WTFL (TOT)	ns	ns	ns	ns	ns	ns	ns	ns	ns**
SMFL (TOT)	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns, $p > 0.05$; + or -, $0.05 \geq p > 0.01$; ++ or --, $0.01 \geq p > 0.001$; +++ or ---, $p \leq 0.001$

A = adult; YOY = young-of-the-year; TOT = total adult and juvenile; MGS = mean grain size; DO = dissolved oxygen in water; FP = fish plant effluent outfall;

4SSB = fourspine stickleback; 3SSB = threespine stickleback; MUMI = mummichog; SILV = Atlantic silverside; SASP = sand shrimp; GRSP = grass shrimp; WTFL = winter flounder; SMFL = smooth flounder

* $\rho_s = 0.348$, $p = 0.053$

** $\rho_s = 0.375$, $p = 0.059$

Table 9. Antigonish Harbour Spearman rank correlation results between the most dominant species, the species richness, the total abundance of animals and different environmental factors.

Species	Temperature	Salinity	DO	Organic content	Moisture content	MGS	Eelgrass coverage	Algae coverage
Sp. richness	ns	-	ns	ns	-	ns	ns	ns
Abundance	ns	ns	+	ns	ns	ns	ns	ns
4SSB (A)	ns	---	ns	ns	ns	ns	+	ns
3SSB (A)	ns	ns	ns	ns	ns	ns	++	ns
MUMI (YOY)	ns	ns	ns	ns	ns	ns	ns	ns
MUMI (A)	ns	ns	ns	ns	ns	ns	ns	ns
SILV (YOY)	ns	ns	ns	ns	-	ns	ns	ns
SILV (A)	ns	ns	ns	ns	ns	ns	ns	ns
SASP (A)	ns	++	ns	ns	ns	ns	-	-
GRSP (A)	ns	ns	ns	ns	ns	ns	ns	ns
WTFL (TOT)	-	ns	ns	ns	ns	ns	ns	ns
SMFL (TOT)	ns	ns	ns	ns	ns	+	ns	ns
GRCR (A)	ns	++	ns	ns	ns	ns	ns	ns

ns, $p > 0.05$; + or -, $0.05 \geq p > 0.01$; ++ or --, $0.01 \geq p > 0.001$; +++ or ---, $p \leq 0.001$

A = adult; YOY = young-of-the-year; TOT = total adult and juvenile; MGS = mean grain size; DO = dissolved oxygen
 4SSB = fourspine stickleback; 3SSB = threespine stickleback; MUMI = mummichog; SILV = Atlantic silverside; SASP = sand shrimp; GRSP = grass shrimp; WTFL = winter flounder; SMFL = smooth flounder, GRCR = green crab

Table 10. Basin Head lagoon Spearman rank correlation results between the most dominant species, the species richness, the total abundance of animals and different environmental factors.

Species	Temperature	Salinity	DO	Organic content	Moisture content	MGS	Eelgrass coverage	Algae coverage
Sp. richness	-	ns	ns	ns	ns	ns	ns	ns
Abundance	ns	ns	ns	ns	ns	- - -	ns	ns
4SSB (A)	ns	ns	ns	+	++	- - -	ns	++
3SSB (A)	ns	ns	ns	ns	ns	ns	ns	+
MUMI (YOY)	ns	ns	ns	ns	ns	ns	ns	ns
MUMI (A)	ns	-	ns	ns	+	- -	ns	++
SILV (YOY)	-	ns	ns	ns	ns	ns	ns	ns
SILV (A)	- - -	ns	ns	ns	ns	ns	ns	ns
SASP (A)	ns	ns	ns	ns	ns	ns	++	- -
GRSP (A)	ns	ns	ns	ns	ns	ns	ns	ns
WTFL (TOT)	ns	+	ns	ns	ns	ns	ns	ns
SMFL (TOT)	-	ns	ns	ns	ns	ns	ns	ns
GRCR (A)	ns	++	ns	ns	ns	- - -	ns	++

ns, $p > 0.05$; + or -, $0.05 \geq p > 0.01$; ++ or --, $0.01 \geq p > 0.001$; +++ or ---, $p \leq 0.001$

A = adult; YOY = young-of-the-year; TOT = total adult and juvenile; MGS = mean grain size; DO = dissolved oxygen
 4SSB = fourspine stickleback; 3SSB = threespine stickleback; MUMI = mummichog; SILV = Atlantic silverside; SASP = sand shrimp; GRSP = grass shrimp; WTFL = winter flounder; SMFL = smooth flounder; GRCR = green crab

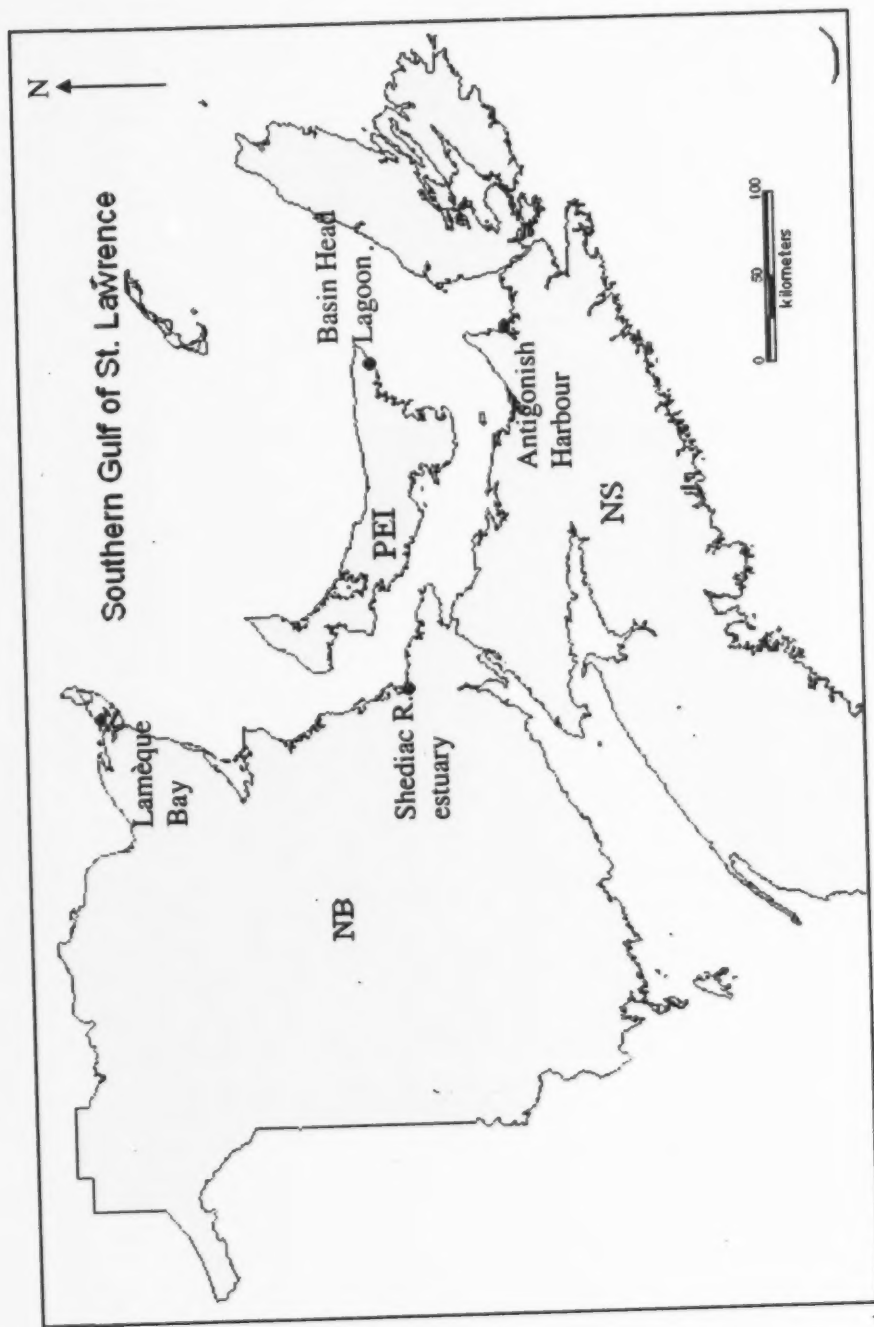


Figure 1. Map of the southern Gulf of St. Lawrence, showing the four sites where the CAMP was launched in 2003.

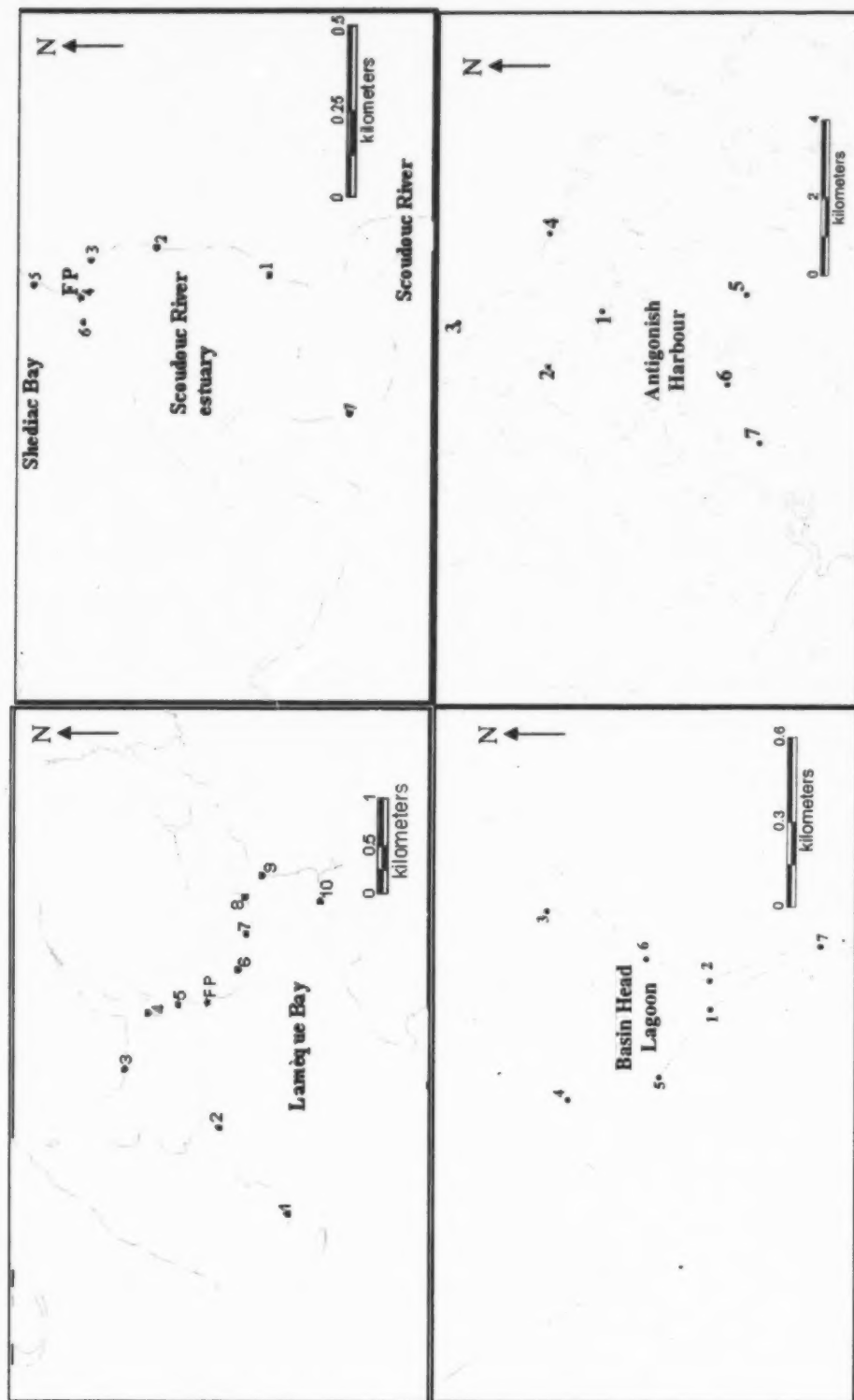


Figure 2. Map showing the four study sites and their sampling stations sampled from July to October 2003. FP = fish plant.

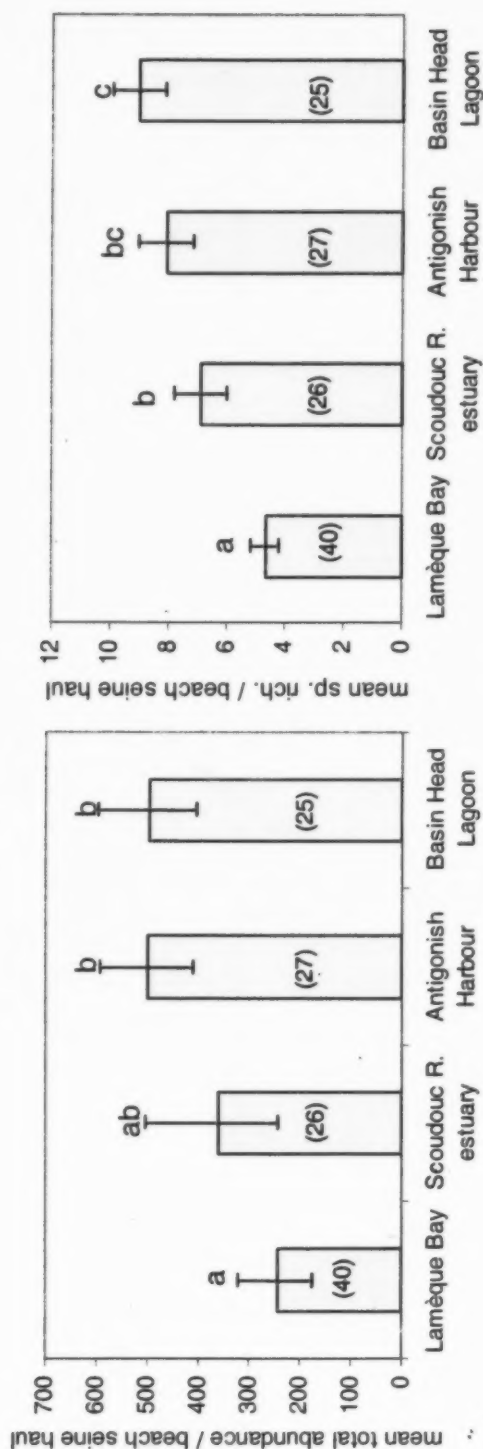


Figure 3. Mean species richness and abundance ($\pm 95\%$ confidence interval) per beach seine haul at the four sites sampled in 2003. Groups sharing common letters are not significantly different ($p > 0.05$, Tukey test). Sample size are placed in parentheses (# stations x # months sampled).

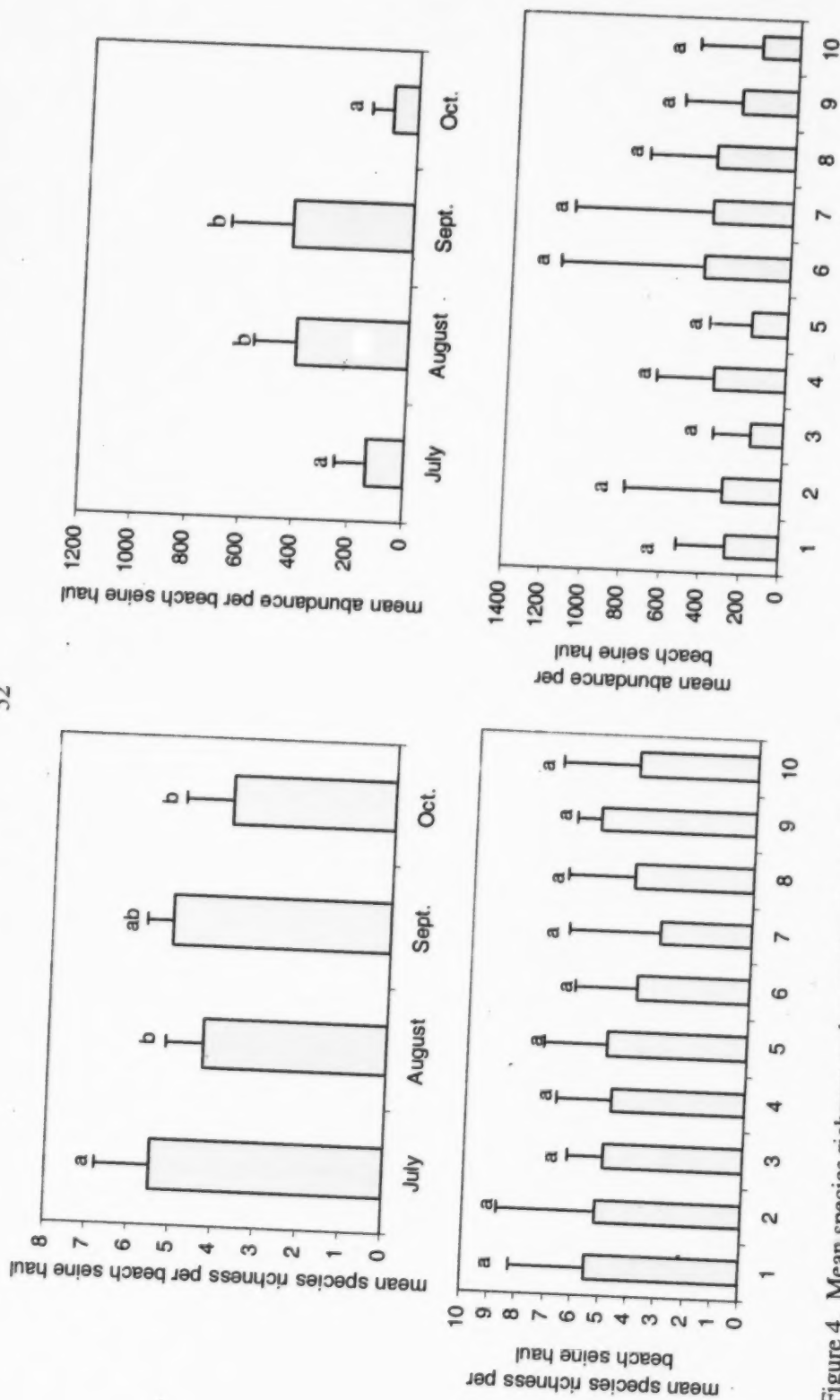


Figure 4. Mean species richness and mean abundance (± 0.95 CI) captured per beach seine haul in Lamèque Bay among the months and the stations sampled. The sample size for each month is 10 (station being pooled as replicates) and for each station is 4 (months being pooled as replicates). Fish plant is located between stations 5 and 6. Groups sharing common letters are not significantly different ($p > 0.05$, Tukey test).

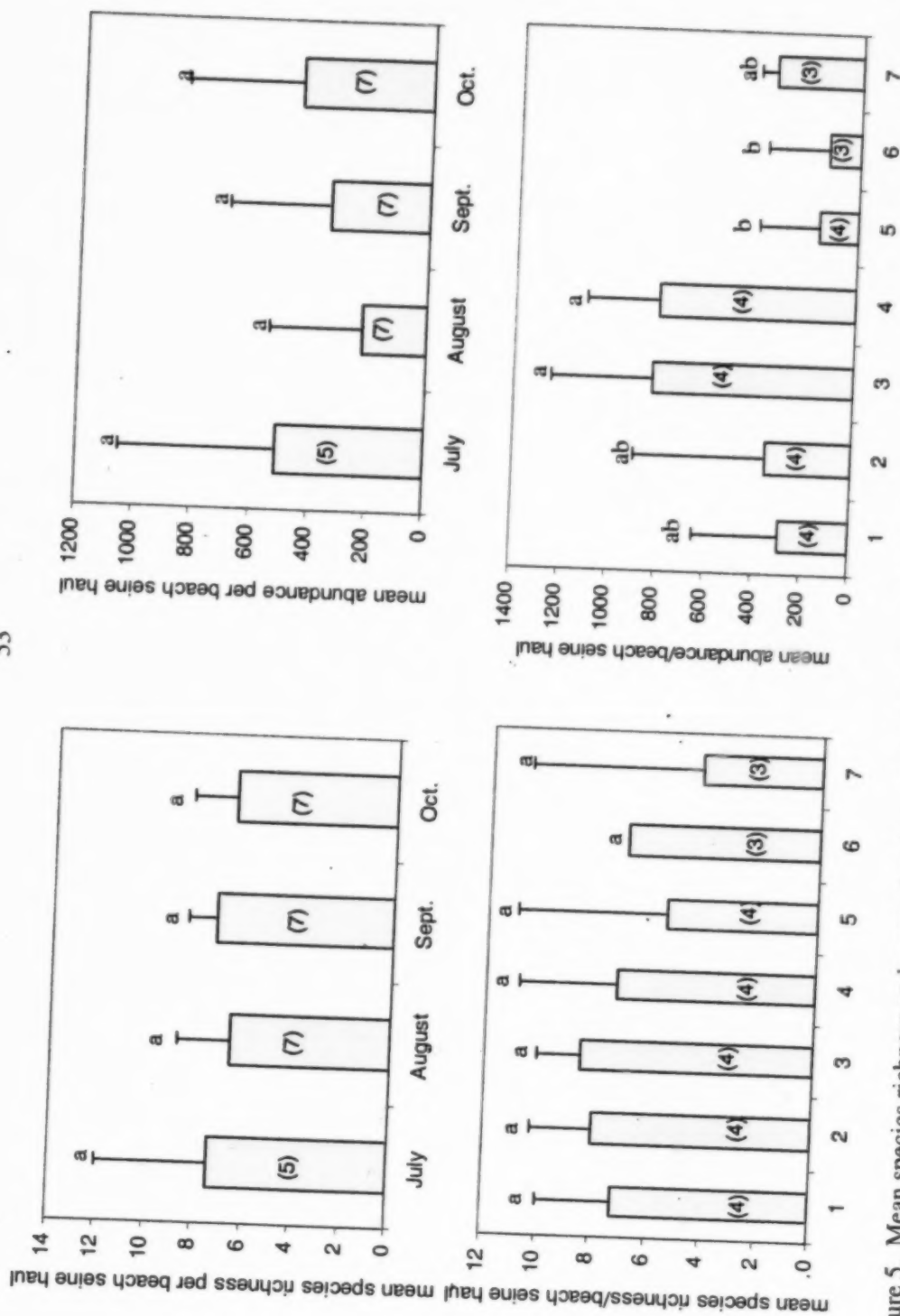


Figure 5. Mean species richness and mean abundance (± 0.95 CI) captured per beach seine haul in Scoudouc R. estuary among the months and the stations sampled. Sample sizes are in parentheses. Groups sharing common letters are not significantly different ($p > 0.05$, Tukey test). Fish plant is located at station 4.

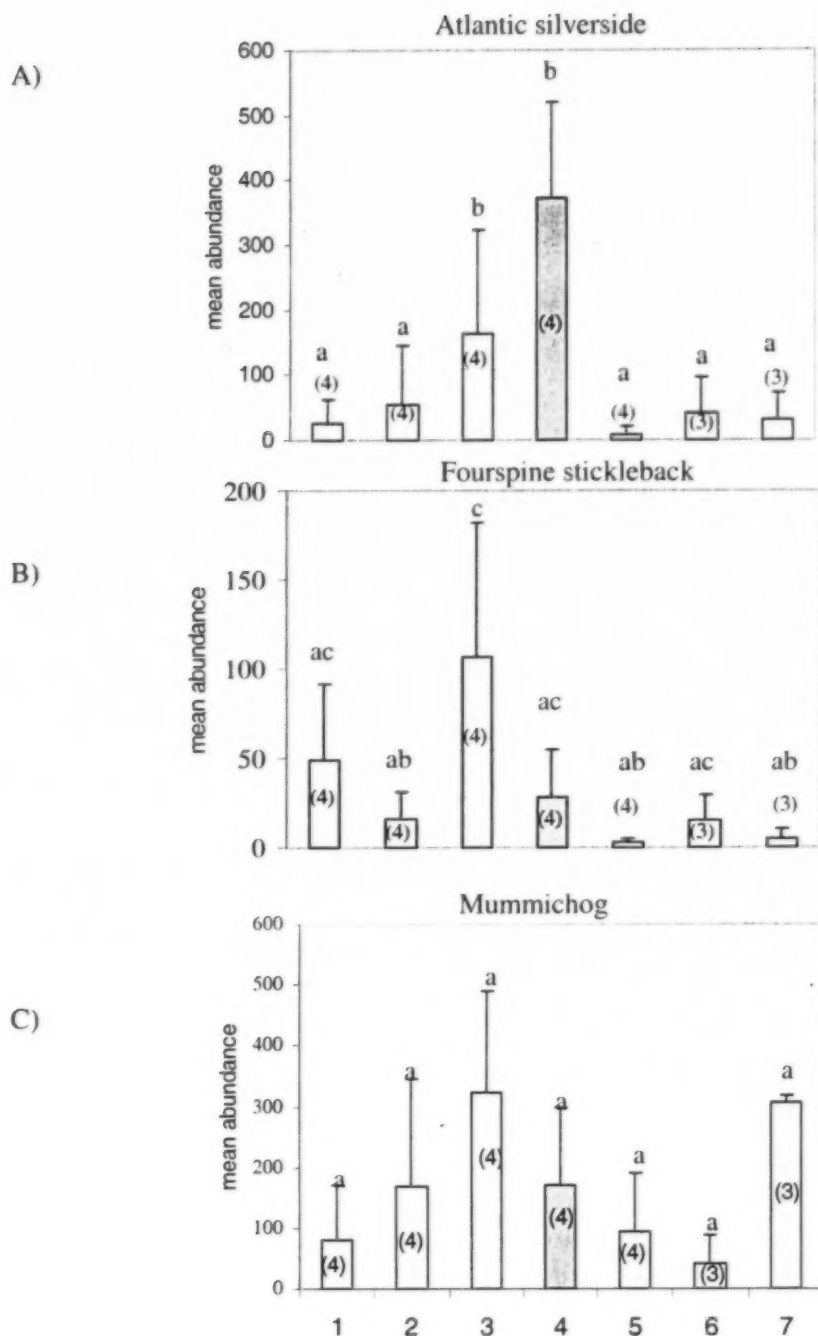


Figure 6. Mean abundance (+95% CI) captured per beach seine haul of A) Atlantic silverside, B) fourspine stickleback and C) mummichog in Scoudouc River estuary caught among the seven stations sampled (i.e., months being pooled as replicates) in 2003. Sample size is in parentheses. Groups sharing common letters are not significantly different ($p > 0.05$, Tukey test). Fish plant is located at station 4.

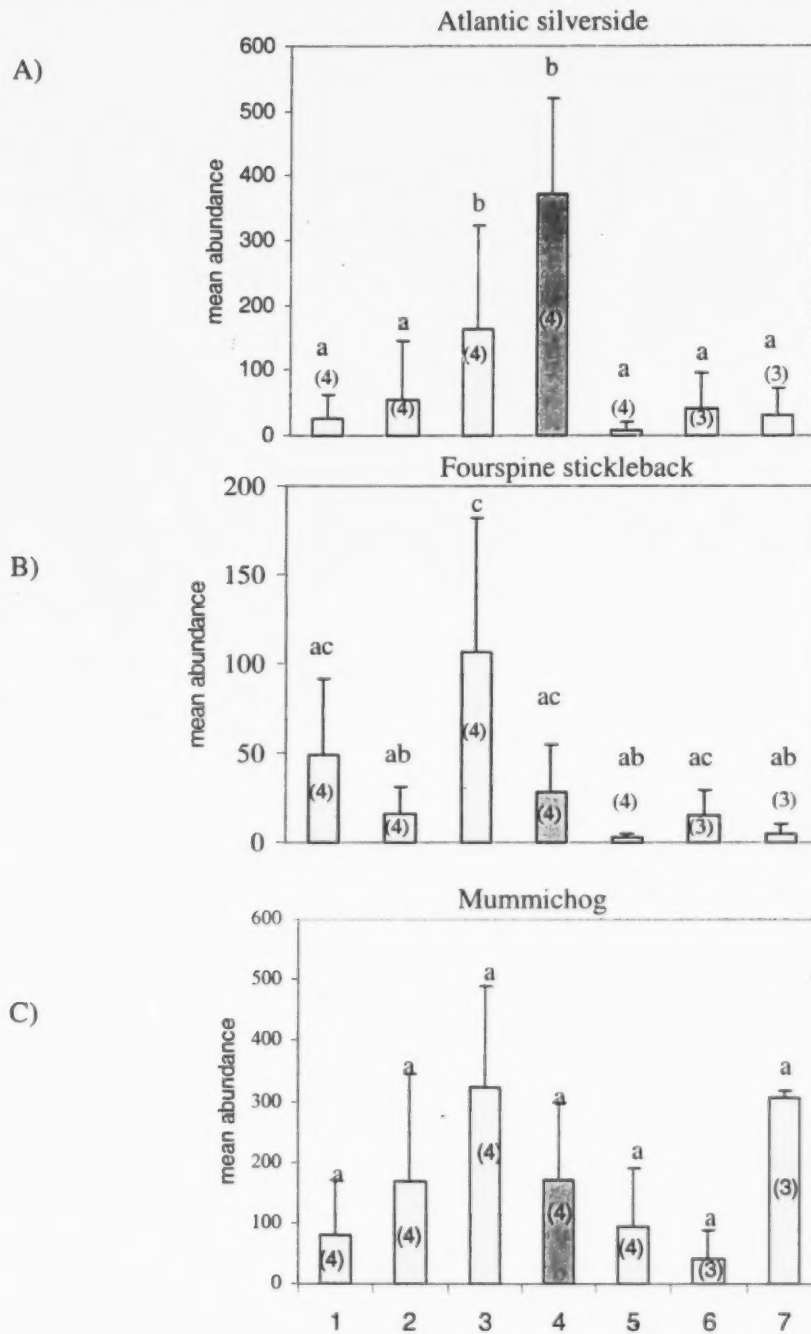


Figure 6. Mean abundance (+95% CI) captured per beach seine haul of A) Atlantic silverside, B) fourspine stickleback and C) mummichog in Scoudouc River estuary caught among the seven stations sampled (i.e., months being pooled as replicates) in 2003. Sample size is in parentheses. Groups sharing common letters are not significantly different ($p > 0.05$, Tukey test). Fish plant is located at station 4.

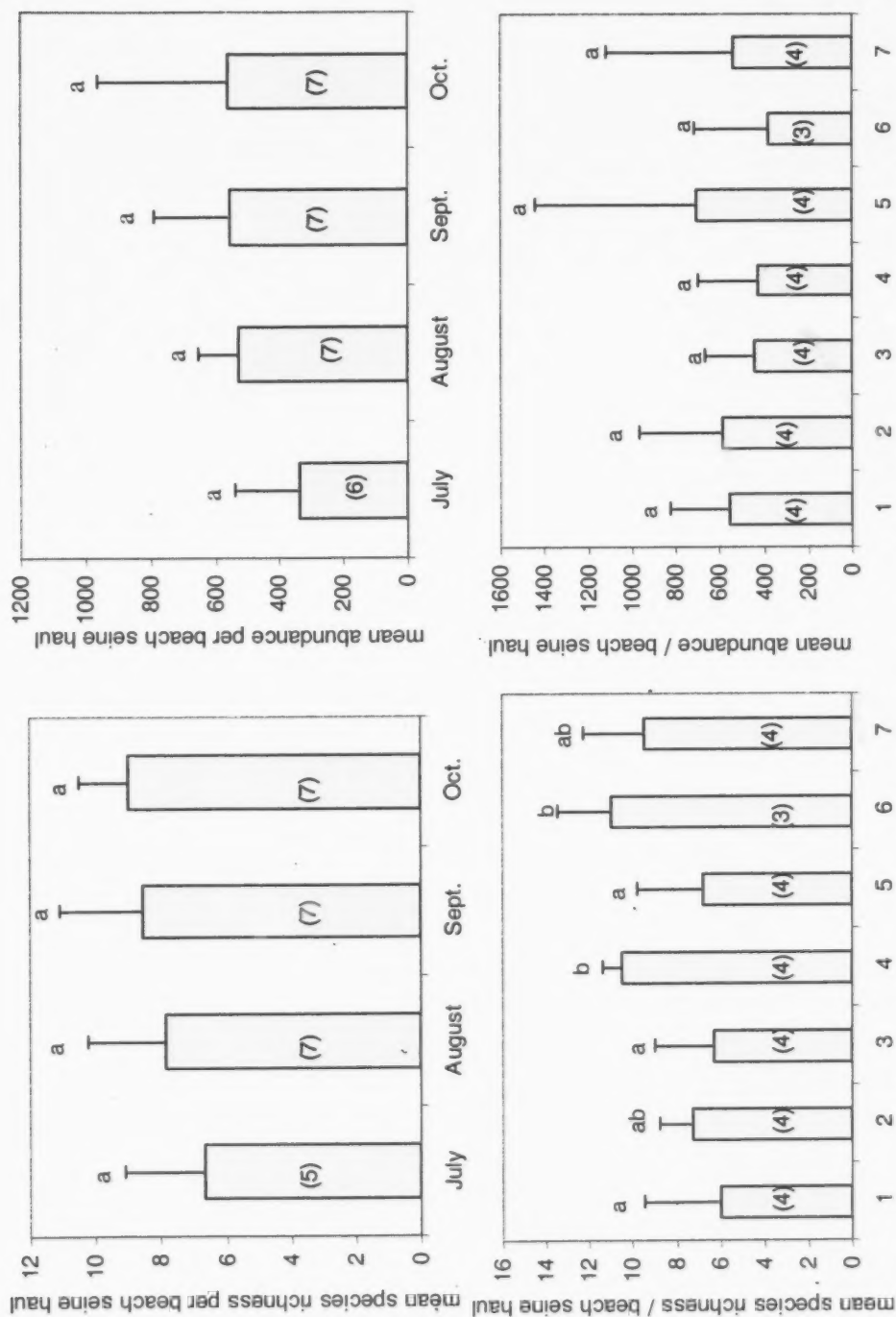


Figure 7. Mean species richness and mean abundance (± 0.95 CI) captured per beach seine haul in Antigoni Harbour among the months and the stations sampled. Sample sizes are in parentheses. Groups sharing common letters are not significantly different ($p > 0.05$, Tukey test).

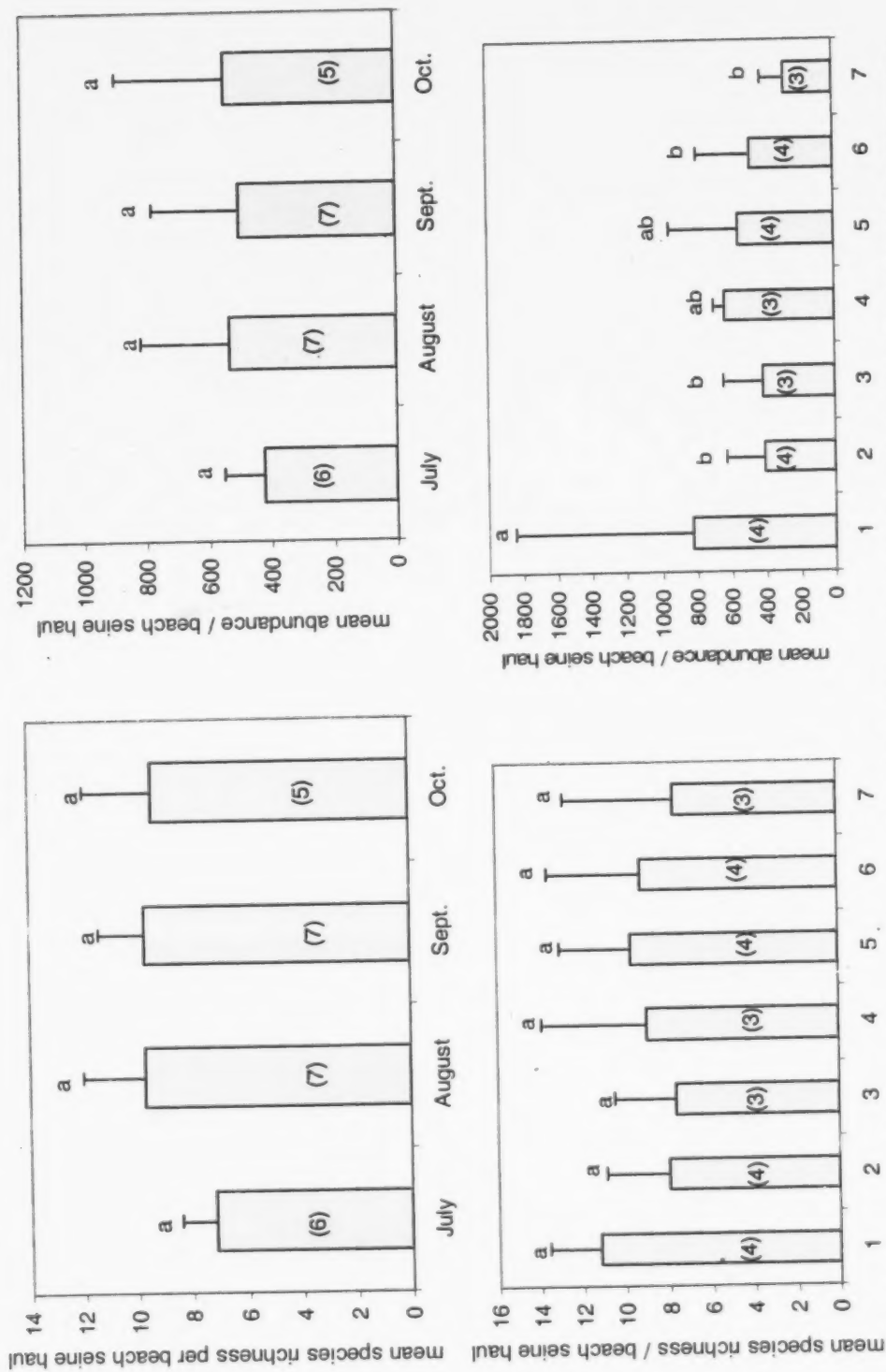


Figure 8. Mean species richness and mean abundance (± 0.95 CI) captured per beach seine haul in Basin Head Lagoon among the months and the stations sampled. Sample sizes are in parentheses. Groups sharing common letters are not significantly different ($p > 0.05$, Tukey test).

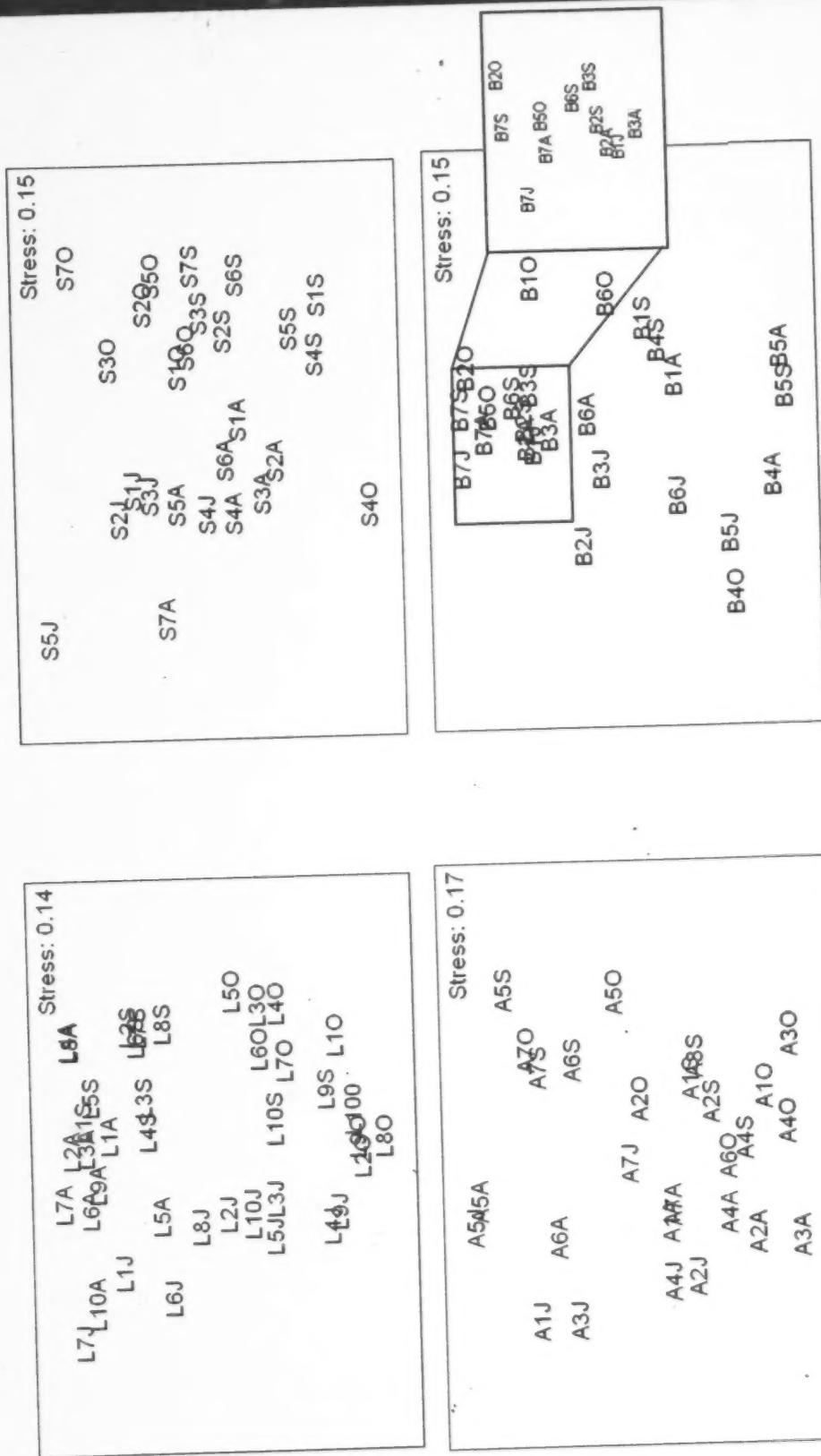


Figure 9. MDS plot of community data from Lamèque Bay (L), Scoudouc River estuary (S), Antigonish Harbour (A) and Basin Head Lagoon (B) at station 1 to 10 for Lamèque Bay and 1 to 7 for the three other sites in the month of July (J), August (A), September (S) and October (O).

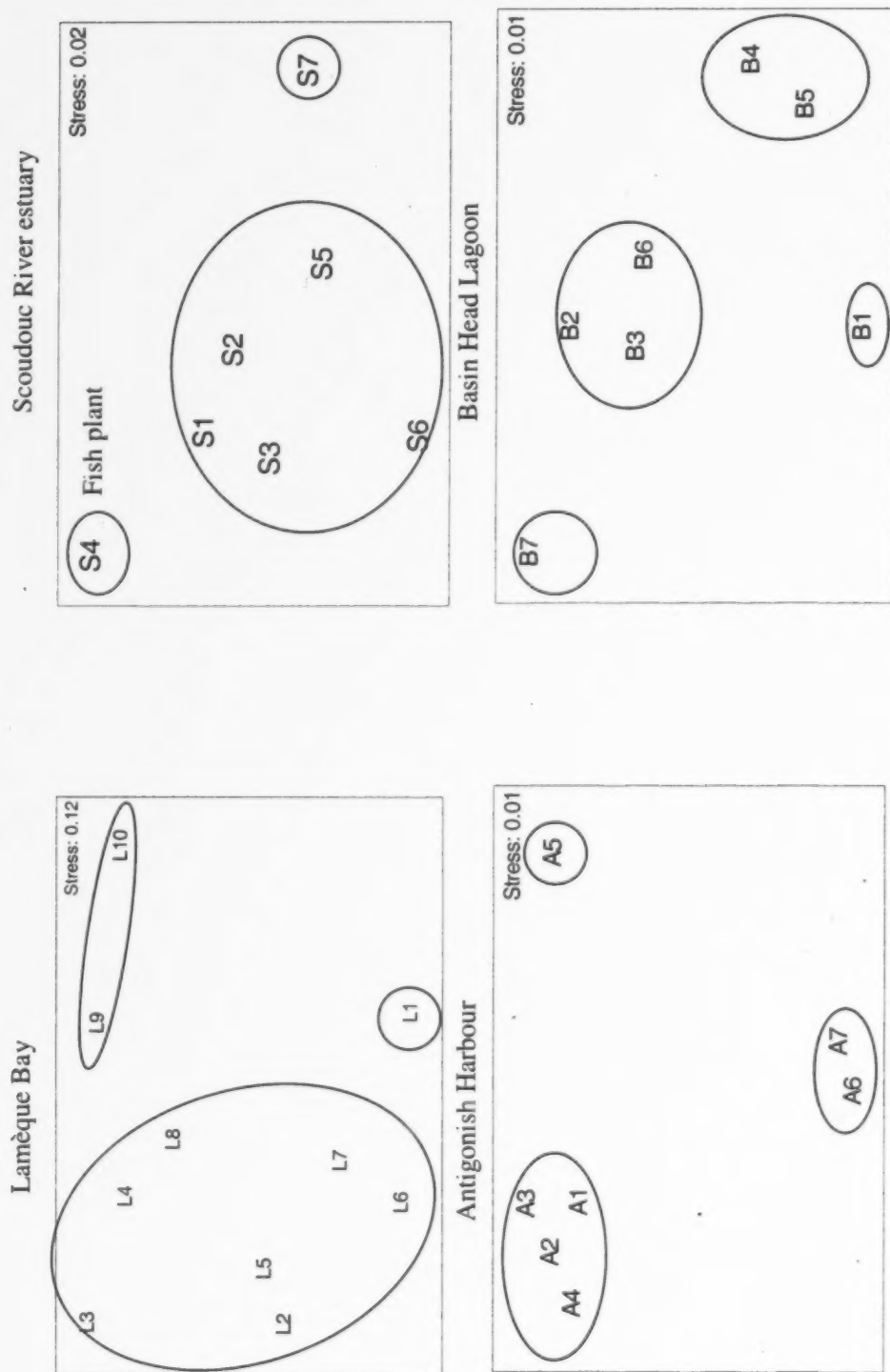


Figure 10. MDS plot of the average (i.e., months being pooled) fish and crustacean community per stations at all four sites in 2003. Ellipses contain stations grouping together at 70% similarity in a cluster analysis (not shown).

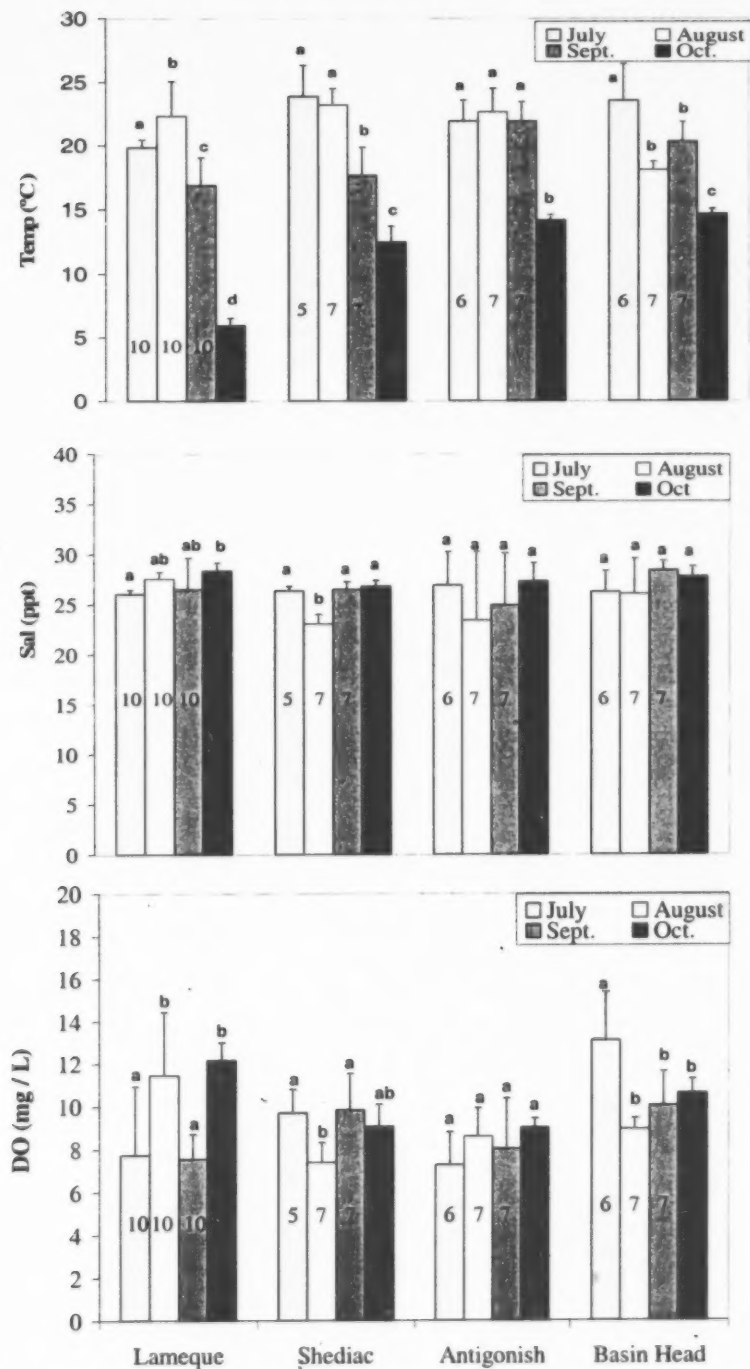


Figure 11. Mean (+SE) temperature, salinity and dissolved oxygen from July to September at the four sites sampled. Numbers indicate sample size. Analyses were performed by site and bars sharing the same letters are not significantly different (Tukey $p > 0.05$).

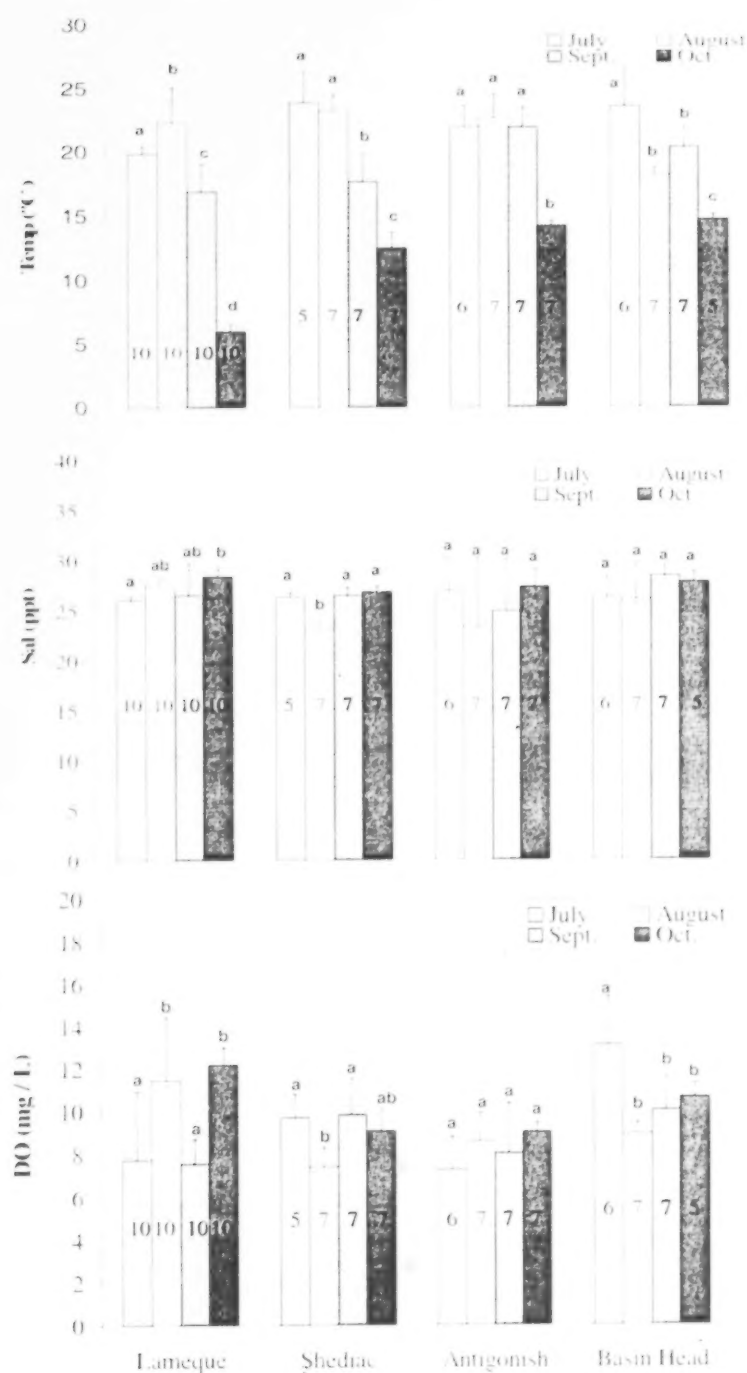


Figure 11. Mean (+SE) temperature, salinity and dissolved oxygen from July to September at the four sites sampled. Numbers indicate sample size. Analyses were performed by site and bars sharing the same letters are not significantly different (Tukey $p > 0.05$).

Appendix 1. Detailed description of when and where species counts were curtailed at 300 in Lamèque Bay (L), Scoudouc River estuary (S), Antigonish Harbour (A) and Baie du Village (B) in 2003.

Site location	Species	stations & months	Total number of samples over 300 / beach seine hauls
Lamèque Bay	Mummichog	L4 - Aug. L6 - Aug., Sept. L7 - Aug., Sept. L8 - July, Aug.	7 / 40 beach seine hauls
	Atlantic Silverside	L1 - Aug., Sept. L2 - Aug., Sept.* L3 - Aug. L4 - Aug., Oct. L5 - Sept. L6 - Aug., Sept.* L7 - Aug., Sept.* L8 - Aug. L9 - Aug.	14 / 40
	Sand shrimp	L10 - Sept.	1 / 40
Scoudouc R. estuary	Mummichog	S2 - July, Oct. S3 - Sept., Oct. S4 - July S7 - Aug., Sept., Oct.	8 / 26 beach seine hauls
	Atlantic Silverside	S3 - Aug., Oct. S4 - Aug., Sept., Oct.	5 / 26
	Threespine stickleback	S4 - Oct.	1 / 26
Antigonish Harbour	Mummichog	A1 - July, Sept. A2 - Oct. A3 - July A5 - July, Aug., Sept., Oct. A7 - Oct.	9 / 27 beach seine hauls
	Atlantic silverside	A4 - Aug. A5 - Aug.	2 / 27
	Fourspine stickleback	A5 - Oct.	1 / 27
	Sand shrimp	A1 - Aug., Sept., Oct. A2 - July, Aug., Sept., Oct. A3 - Aug., Sept. A4 - Oct.	10 / 27
Baie du Village	Mummichog	B2 - July B4 - Aug., Oct. B5 - July, Sept.	5 / 25 beach seine hauls
	Atlantic silverside	B1 - Oct.	1 / 25
	Fourspine stickleback	B1 - Aug., Sept. B4 - Aug. B5 - Aug., Sept. B6 - Oct.	6 / 25
	Sand shrimp	B1 - July, Aug., Sept., Oct. B2 - July, Aug., Sept. B3 - July, Aug., Sept. B6 - Aug., Oct. BH7 - July, Aug.	14 / 25

* indicates when the YOY and adult fish were both curtailed at 300.



